Weeds

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Weeds

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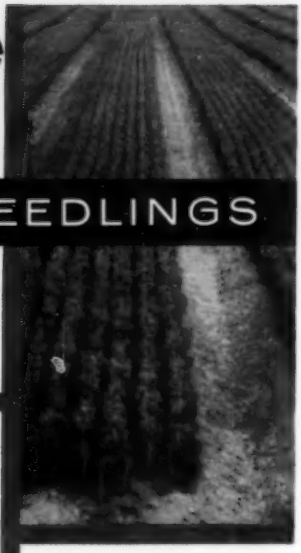

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Weeds

JOURNAL OF THE WEED SOCIETY OF AMERICA

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The Challenges of Modern Weed Control[1]

W. B. ENNIS, JR.[2]

WEEDS have plagued man in his agricultural pursuits since biblical times in spite of backbreaking efforts to control them by hand and mechanical methods. At this second meeting of the Weed Society of America it appears appropriate to review briefly some of the modern accomplishments in weed control and to take stock of future needs.

Today, weeds still limit low-cost production of food, fiber and feed crops on all lands where they occur. Also, weeds present costly control problems on numerous industrial sites and other non-crop areas and they adversely affect the health of millions of our population by causing allergies and other ailments. The costs of controlling weeds and the losses from failing to control them are borne by all facets of private and public life. In short we all have to pay the costs of weed control.

Although much progress has been made in improving weed control methods, weeds challenge agriculturists today just as they did a half century ago.

The challenges appear to be even greater today because of the continuing upward spiral of labor and other production costs which increasingly limit a producer's net income. Moreover, the introduction of new and powerful chemical tools to attack weed problems has opened new horizons that should challenge the imagination and initiative of all weed workers. But are we meeting such challenges aggressively enough?

Losses due to weeds. Our estimated annual national loss of 5 billion dollars due to weeds is among the most serious problems facing the agricultural industry and many phases of other industries. Allergies due to weeds are of concern to the whole population.

Although comprehensive and adequate data are not available on the losses caused by particular weeds in various crops and situations, some limited data serve to indicate the economic threat weeds pose

[1]Excerpts from presidential address delivered before the second meeting of the Weed Society of America, Memphis, Tennessee, January 12–15, 1958.

[2]President, Weed Society of America, 1956–1958; Agronomist, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Beltsville, Maryland.

in producing crops. For example, in Montana, Canada thistle (*Cirsium arvense* (L.) Scop.) infestations of 3–5, 20–25, and 40–45 shoots per 16 square feet reduced yields of hard red spring wheat 4.2, 9.0, and 15.3 bushels per acre, respectively.[3] Downy brome (*Bromus tectorum* L.) infestations in alfalfa in Washington reduced hay yields 1 ton per acre.[4] Fifteen mustard plants (*Brassica* sp.) per square foot reduced yields of oats 11 bushels per acre in New York.[5] Onion growers in Colorado currently spend about $60 per acre for handweeding,[6] and in Wyoming the cost of weeding sugar beets is about $23 per acre (1).

The annual cost of weed control in cotton in Mississippi by handhoeing and conventional cultivation ranged from about $11 to $18 per acre between 1954 and 1956, and labor requirements for weed control (including cultivation) ranged from 20 to 41 man-hours per acre (4).

Examples of this sort indicate that weeds are critical problems in crop production today. They clearly offer a challenging need for the development of satisfactory materials and methods to lower the cost of production, to reduce human drudgery, and to provide growers with greater dollar returns on their investments.

What progress are we making toward meeting these modern day challenges? What are some of the accomplishments that are measures of past progress?

Benefits from controlling weeds. Progress is being made in reducing the costs of weeds in producing certain crops. Savings are also being made in controlling weeds on non-croplands. Data on the benefits of controlling weeds are not adequate—but a few examples will indicate the potential that modern chemical weed control offers to agriculture.

The control of big sagebrush (*Artemisia tridentata* Nutt.) with herbicides costing $2.25 to $3.25 per acre has given a net gain estimated at $1.68 an acre in Oregon.[7] If such a treatment was applied on one-fourth of the 96 million acres of range infested with big sagebrush an annual gain of over 40 million dollars might be realized. It is estimated that control of big sagebrush would be effective to some degree for at least 10 years; thus the gain from control would be about 10 times as great as the figure indicated.

The control of barnyard grass (*Echinochloa crusgalli* (L.) Beauv.) in rice by use of isopropyl N–(3–chlorophenyl)carbamate [CIPC] as a delayed pre-emergence herbicide has given striking economic gains. In Arkansas an average gain of $67 per acre was obtained in

[3]Unpublished data. J. M. Hodgson, Crops Research Division, ARS, USDA, Bozeman, Montana.

[4]Unpublished data. V. F. Bruns, Crops Research Division, ARS, USDA, Prosser, Washington.

[5]Unpublished data. M. M. Schreiber, Crops Research Division, ARS, USDA, Ithaca, New York.

[6]Unpublished data. C. M. Drage, Colorado State University, Fort Collins, Colorado.

[7]Unpublished data. D. N. Hyder, Crops Research Division, ARS, USDA, Burns, Oregon.

7 experiments from 1955 to 1957. By controlling coffee weed (*Sesbania exaltata* (Raf.) Cory) and curly indigo (*Aeschynomene virginica* L.) with 2,4–dichlorophenoxyacetic acid [2,4–D] in foundation, registered and certified rice, gains as high as $413, $113, and $38 per acre, respectively, can result.[8] These high returns are possible because without weed control the rice becomes infested with seeds of these weeds and it must be sold at a low price for milling and not at premium prices for seed rice.

The control of weeds in flax with trichloroacetic acid [TCA] and 2–methyl–4–chlorophenoxyacetic acid [MCPA] in Minnesota has given an average gain of about $15 per acre over the period of 1950 to 1956.[9]

Control of winter weeds in spinach in Mississippi between 1953 and 1957 resulted in an average gain of $162 per acre.[10] Other studies conducted in Mississippi between 1954 and 1956 showed that the use of herbicides in cotton reduced weed control costs $2 to $6 per acre and reduced labor requirements 16 to 35 man-hours per acre. Yields tended to be higher on the chemically treated plots, probably due to better control of weeds, with the result that the use of herbicides led to monetary gains averaging about $21 per acre and ranging from a gain of less than $1 to $46 per acre.[11]

The opportunities are indeed challenging for additional contributions through developments to control weeds not only on cropland but also on utilities and highway rights-of-way, drainage and irrigation ditches, farm ponds, recreational lakes, wildlife refuges, parks, and other areas.

Trends in research support. The progress that has been made in weed control is directly related to the research effort that has been given to weed control. This view is borne out by the large number of promising herbicides that have been recommended for use since significant emphasis was placed on herbicide research by private and public agencies beginning about 10 years ago.

Emphasis on weed research by public and private agencies has increased markedly since 1950. The public funds devoted to such research are indicative of the growth pattern (Table 1). In 1950 the State Agricultural Experiment Stations spent a total of $623,000 for weed control research. In 1957 state expenditure for weed research had increased to $1,646,000. Similar growth has occurred in the weed research program of the Agricultural Research Service, U. S. Department of Agriculture. Beginning with $181,283 in 1950 federal research expanded to $660,660 in 1957. There has been a growth in

[8]Unpublished data. R. J. Smith, Jr., Crops Research Division, ARS, USDA, Stuttgart, Arkansas.

[9]Unpublished data. R. S. Dunham, University of Minnesota, St. Paul, Minnesota.

[10]Unpublished data. C. G. McWhorter and S. W. Bingham, Crops Research Division, ARS, USDA and Mississippi Agricultural Experiment Station, Stoneville, Mississippi.

[11]Unpublished data. J. T. Holstun, Jr., C. G. McWhorter, O. B. Wooten, Jr. and G. B. Crowe, Agricultural Research Service, USDA, and Mississippi Agricultural Experiment Station, Stoneville, Mississippi.

Table 1. Public funds directly supporting research on weeds in the United States.

Fiscal year	Agricultural experiment stations			Agricultural Res. Service, USDA[a]	Grand total
	Federal grant	Non-federal	Total		
1950	$ 97,000	$ 526,000	$ 623,000	$181,283	$ 804,283
1951	141,000	560,000	701,000	176,071	877,071
1952	158,000	677,000	835,000	185,320	1,020,320
1953	166,000	745,000	911,000	228,678	1,139,678
1954	159,000	863,000	1,022,000	332,789[b]	1,354,789
1955	302,000	970,000	1,272,000	361,400	1,633,400
1956	427,000	951,000	1,378,000	433,450	1,811,450
1957	540,000	1,106,000	1,646,000	660,660[c]	2,306,660

[a]Funds allocated for agricultural engineering research not included.
[b]Transfer of activities from U. S. Forest Service and Soil Conservation Service included.
[c]Transfer of activities from U. S. Department of the Interior included.

the number of full-time U. S. Department of Agriculture workers from 17 in 1951 to 60 professional positions today involved in cooperative research in 27 States.

The 2.3 million dollars of public funds currently spent on weed research represents less than 0.05 percent of the annual 5 billion dollar loss due to weeds or about $0.05 invested in research per $100 loss.

Research by the chemical industry also has increased markedly during the present decade as evidenced by the large number of new herbicides introduced and the increased number of workers in research and development work. The importance of the contributions of industry toward advancing weed control cannot be overemphasized.

Adoption of weed control practices. Within about one decade the results of research conducted by weed workers have found a receptive audience among farmers and others interested in controlling weeds. The total estimated acreage sprayed for control of weeds now exceeds the acreage sprayed and dusted for insects and plant diseases. For example, it is estimated that 17 to 18 million acres of small grains, 10 to 12 million acres of corn, 2 to 3 million acres of pasture and rangeland, 275,000 to 300,000 acres of cotton and about 2 million acres of other cropland are treated annually for weed control (3). In 1955 an average of $41 per farm was spent on herbicides by farmers who produced products valued in excess of $10,000 and $1.59 per farm for those who produced less than $1,200. The average expenditure per farm on a national basis was about $10 (2).

These developments have been made possible by the work of extension and technical sales and development personnel in interpreting research findings and gaining acceptance of them by farmers. Equally important has been the work of regulatory personnel in administering laws pertaining to weeds and herbicides and the activities of public health workers in promoting weed control programs. All these activities are interwoven to protect the public health and welfare. I am hopeful that the work of personnel concerned with these phases of weed control can be expanded in a coordinated manner in the future. It is encouraging that the number of exten-

sion weed specialists is increasing and more regulatory personnel have become involved with weed control matters. The expanded work of these specialists will surely result in even greater adoption of modern weed control techniques by farmers. This expansion should also relieve research men from extension-type duties and give them more opportunity for research.

Needs in weed control. What is the status of basic research in the weed control field? I believe that it is obvious to most scientists that we must have a pool of basic facts and understanding upon which to develop weed control practices and sound extension, regulatory and public health programs. Our future progress undoubtedly will depend in large measure on the storehouse of knowledge that is developed in sound laboratory and field studies. If we lag in conducting basic studies in this decade the growth and development of weed control will suffer one, two, or perhaps three decades hence. Indeed basic research must turn many unturned keys to slant the graph of progress toward more weed control developments of a practical nature. Fundamental research must have equal emphasis with applied research or we may completely exhaust the reservoir of basic information in developing applied approaches to problems.

Basic research in weed control must be strengthened. We have a distressingly poor understanding of the mechanisms of herbicidal action. The need is acute for developing through research a knowledge of the physiological processes involved in the response of weeds and crop plants to herbicides as influenced by environmental factors. A more exact knowledge of the mechanisms involved in conditioning leaf, stems, and root surfaces for efficient penetration of chemicals is needed to provide a sound basis for the development of practical and reliable procedures for using herbicides to control weeds. Equally challenging are the needs for synthesis and discovery of new principles that will open new frontiers for practical developments.

Another deficient area in weed control is the lack of properly trained personnel. We are not training an adequate number of persons to conduct weed control research, to carry out proper educational programs, and to administer regulatory and development programs. Every effort should be made by members of our Society, both individually and collectively, to encourage more promising students to choose weed control as their major field of study and work. We need more educational and extension weed specialists that can disassemble and reassemble research information in order for farmers to use it in their practical operations. Weed control courses need to be offered to undergraduate students that are to become county agents, vocational agriculture teachers and other leaders in agriculture. The latter groups are in an excellent position to provide the local leadership needed to gain adoption of improved weed control practices that will benefit farmers. I feel that wider adoption of many currently recommended uses of herbicides would occur if adequate extension programs were in effect. Such adoption could alleviate innumerable serious weed problems on many farms of this country.

Another area in which we are lagging is in the development of adequate cost data than can be used not only in planning and conducting sound and effective programs of research but also in educating the public at large on the importance of weeds to our nation. We need to take the offensive in stimulating an awareness of the importance of weeds in the nation's economy. Much can be done in this regard if more reliable and specific cost data can be obtained on particular weeds and weed-crop situations. In connection with our present program of research some extra effort should be made to solicit assistance of agricultural economists and others that may become interested in cooperative studies on losses caused by weeds and benefits that may result from their control.

In our enthusiasm to develop improved chemical techniques for controlling weeds, we must not lose sight of bringing other control measures to bear on weeds. Are we overlooking the advantages and the possibilities of improving the cultural methods of controlling weeds? Are we taking advantage of all the natural hazards to the development of weeds? Do we know the diseases that attack important weeds? What parasites and natural predators attack troublesome weeds? These and other aspects should not be overlooked entirely in favor of developing chemicals to control weeds. It is equally important that we be cognizant of the activities of our neighbor scientists concerned with one aspect or another of the highly complex and diversified agricultural industry. Our approach to problems must not be too narrow. Practices we recommend must fit into a scheme of production practices involving agronomic, horticultural, engineering, and other phases. Appropriate workers in these fields, especially agricultural engineers, should be encouraged to participate in the activities of our Society. We in turn must keep them currently posted on our work and achievements. There must be real teamwork between weed workers and technical personnel in allied fields if best progress is to be made toward providing producers with sound and efficient recommendations for improved weed control practices.

The Weed Society of America should and must play a key role to insure that weed control as a new science develops properly. WSA must not be relegated to the role of a holding body for member conferences. In contrast, the Society must assume leadership in this field. It must be influential professionally, sound financially, and efficient operationally and provide services to fulfill the needs of the Society members. For this to occur we must support WSA both individually and collectively and make a concentrated effort to expand the membership.

State, Federal, and private agencies must continue to cooperate, indeed be partners, if progress in this field is to continue. No matter what the future developments may be the need for close cooperation and better understanding between personnel in research, education, extension, regulatory and public health phases, and the chemical industry will increase. I am hopeful that the Weed Society of Amer-

ica will play a signal role in achieving a completely harmonious and productive relationship.

We are moving ahead. The art of weed control has turned the corner. Has weed research of today turned with it? Have the extension, regulatory and public health phases of weed control pointed their activities to serve properly this new direction weed control has taken? As weed workers we must periodically take inventory of current needs and set our sights on proper goals to insure fulfillment of these needs.

The prospects are indeed bright for the development of economical measures to replace human energy in controlling weeds that are so costly and troublesome to agriculture and the nation. Of course, weed control is not yet out of the woods. We must put our shoulders to the wheel and work together with the common objectives of making weed control the science that it rightfully should be. I believe we will meet the exciting challenges presented in our new science of weed control. Only time will tell whether our hopes and expectations will become realities.

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Studies on the Absorption and Translocation of Amitrol (3–amino–1,2,4–triazole) by Nut Grass (*Cyperus rotundus* L.)

OTTO ANDERSEN[1]

INTRODUCTION

IN studying herbicides in relation to a complex weed like nut grass (*Cyperus rotundus* L.), it soon becomes clear that high efficiency is attained only if the herbicide is able to penetrate and translocate readily to all parts of the plant, still retaining sufficient toxicity to kill every one of the vital organs.

The present work was conducted to determine the behavior of amitrol with regard to penetration, translocation and possible accumulation at the vital organs of the nut grass plant. It seemed that accumulation, with a resulting increase in concentration, might explain the preferential action of amitrol upon the growing points.

Day[2] presented a clear picture of the concepts that explain the mechanism of normal solute translocation in the plant. He considered high velocities of transport to be the principle obstacle confronting workers who propose mechanisms of solute translocation. Advocates of a diffusion type of movement believe that molecules are accelerated through a relatively stationary medium by the application of metabolic energy either by means of protoplasmic streaming (5) or by direct acceleration of the diffusion process (13). On the other hand the concept of pressure-flow accounts for high velocities by assuming that the phloem sap moves rapidly as a mass through the sieve tubes (1, 2). Thus far complete direct evidence for either concept has not been attained, but certain conclusions can be drawn on the basis of indirect evidence.

As Day points out, both the results from his own experiments and those obtained by Weaver and DeRose (18), Mitchell and Brown (14), Rohrbaugh and Rice (16), and Weintraub and Brown (20) have shown the direction and velocity of translocation of 2,4–D (2,4–dichlorophenoxyacetic acid) from leaves to be independent of its concentration gradient and correlated with the concentration gradient of food materials. As a second indication, Day points out that killing of the phloem of the hypocotyl delays translocation from the leaf into the epicotyl; this may be interpreted as a direct demonstration of mass-flow. Finally he stated that removal of the leaf blade prevented translocation from the petiole, which likewise indicates that mass-flow is the mechanism of transport since translocation is stopped by removing the source of moving sap.

Hay (9) and Hay and Thimann (11) disagree with the above

[1]Assoc. Prof. Horticulture, U.R.E.M.G., Viçosa, Minas Gerais, Brazil.

[2]Day, Boysie E. Absorption and translocation of 2,4–dichlorophenoxyacetic acid by bean plants. Ph.D. dissertation. University of California, Davis, California. 1950.

conclusion stating that the relation between sugar and translocation of 2,4–D cannot be interpreted as being causal, and acting through simple osmotic forces, as required for the mass-flow theory. The effect of carbohydrates on transport of 2,4–D in the phloem is rather that of a metabolic component.

Reference to accumulation of solutes in specific sites within the plants was given by Shaw and Samborski (17) who studied the accumulation of glucose–1–C^{14} at parasitic infections. When excised, parasitized leaves were placed with their bases in a solution of glucose–1–C^{14} for sufficient time, autoradiography showed that sugar accumulates strongly at colonies of obligate parasites. It paralleled the respiration rate and increased progressively with the development of the parasites. In the case of mildew, accumulation was inhibited by sulfur dust, sodium azide, 2,4–dinitrophenol and, reversibly, by anaerobiosis. It was, therefore, dependent on aerobic respiration.

The experiments described below will show how the very useful techniques developed by Crafts and coworkers (McCarthy, Kean, Pallas, Stewart, Yamaguchi) were employed to aid the understanding of translocation as an important aspect of the physiological action of amitrol on nut grass plants.

MATERIALS AND METHODS

The radioactive amitrol employed had a C^{14} atom on the 5-position. Its original activity was 1.27 millicuries (mc.) per millimole.[3]

Preparation of the plant material. The plants were grown in culture solutions under conditions which were varied according to the aspect being studied. As a rule the plants were started as transplants in quart-size Mason jars, where they were kept until they attained a size which approached the rosette stage with 8 to 12 leaves.

For two experiments the plants were at the stage described above; for other experiments, it was desirable to employ a chain of three plants for tests on translocation. These chains were obtained by allowing the plants which had reached the stage described above, to grow for an additional period, until two daughter plants were produced by each initial (mother) plant. At this stage an inflorescence was also produced by the older plant.

One to two weeks before application of the radioactive herbicide, such chains (three plants each) were transplanted to a 6 x 18 inch glass cylinder (see Figure 1) having the inner surface covered with filter paper. Only the tips of the longest roots reached the level of the Hoagland's solution supplied to the cylinder, but the wet filter paper furnished a convenient supply of solution for the maintenance and growth of the plants. A fairly stiff ¼ inch tube of polyethylene served to hold the plants against the wall of the glass cylinder. This container had its outer surface entirely covered by aluminum foil, while a cover of the same material was used as a lid, fitted around the stems of the plants so that the roots could be kept in the dark.

General procedure for the application of radioactive herbicides.

[3]Supplied by the American Chemical Paint Co., Ambler, Pa.

Figure 1. Nut grass plants growing on filter paper in a 6 by 18 inch glass cylinder for the application of radioactive herbicide by the "drop method".

Yamaguchi and Crafts (22) have described techniques for the preparation of autoradiographs. In the present experiments on *Cyperus*, the procedure followed basically the same techniques but was subjected to certain adaptations due to the specific plant species tested.

When the plants were ready for treatment, a healthy mature leaf was selected on each plant and a ring of lanolin approximately ½ inch in diameter was formed on the adaxial surface at the lower part of the blade. The radioactive herbicide was applied to the leaf surface within the ring as a 10 microliter droplet of solution having an activity ranging from 0.5 to 1.0 microcurie (μc.).

At the end of the scheduled treatment time, the main plant was labelled for identification, the lanolin and remaining chemical were removed with Kleenex tissue, and the area of the application covered with masking tape. The plant was then removed from the culture cylinder and folded so as to fit into a folder paper towel.

An insulated box, internally covered with aluminum foil served as a freezing container. Each paper towel containing a plant was placed in this box and surrounded with dry ice.

After all plants to be killed in a given experiment were collected and frozen, the box was closed and brought to the freezer which was adapted to the freeze-drying operation.

The container used for this purpose was a rectangular steel tank (10 x 16 x 4 inches), having a lid which could be bolted on tightly, and sealed with the aid of a rubber gasket. It contained a shallow

tray at the bottom, for the drying material, calcium hydride. On top of this tray was a wire tray in which the towels containing the frozen plants were piled. This metal tank was adapted to the freezer compartment of a refrigerator in such a way that a pipe extension connected to the back of the tank emerged to the outside, at the back of the refrigerator. This extension was connected to a vacuum pump which operated continually for the time the material was being dried. Normally 4 days sufficed to render the nut grass plants entirely dry.

Being very brittle at this stage, the plants had to be remoistened by placing them for around 1 hour in a closed container having an atmosphere of high relative humidity. Thus they regained their flexibility enabling their parts to be bent into the most convenient shape for mounting on a 9 x 12 inch lithograph paper sheet.

The plants were cemented to glossy lithograph paper with rubber cement, diluted by twice its volume of thinner (benzene). Care was taken because an excess of rubber cement produced a pseudo-autograph on the film. It was also important to avoid touching any of the plant parts with the cementing brush, since this was easily contaminated with the radioactive fragments (trichomes, root hairs, etc.) which smeared over the paper wherever the cement was applied. Such contamination produced a very messy autograph that was difficult to interpret.

Once mounted the plants were pressed so that the upper surface was flattened. This was accomplished by placing the plants against a veneer board and backing the lithograph paper with a layer of two to four blotters. A press described by Yamaguchi and Crafts (22) was used.

Pressed and cleaned of visible excess of rubber cement, the mounted plants were ready to be placed on the X-ray films[4] for autographing. The films were marked for identification. Plants and films were then placed together in the following sequence: First a thick wooden board, then a ¼ inch thick sponge-rubber sheet followed by the mounted plant with the face up, the film, an aluminum-covered veneer board, again a film, a mounted plant face down, a sponge rubber sheet, a mounted plant face up, and so on. At the end of a pile which contained around 30 mounted plants, a second board of thicker wood was placed. The whole pile was then bound together with two flexible belts that maintained a steady pressure. The package was placed in a dark box for 28 days, after which the film was developed.

I. Experiments Employing Radioactive Amitrol.

A. *Time series testing for rate of penetration and translocation and for sites of accumulation of amitrol at definite periods after the application.*

In the time series, 17 chains of nut grass plants as described above, were selected. One plant was kept as a control and the other ones distributed into eight duplicated treatments as follows:

[4]Kodak no screen X-ray safety film.

Keeping the amount of amitrol constant, the variable was the time allowed for the action of the herbicide previous to the killing of the plants; treatment times were ½, 1, 1½, 2, 2½, 3, 3½ and 4 hours, respectively.

The treatments received two droplets each (20 microliters with 1.0 μc. activity) of a 8,450 ppm amitrol solution. The applications were made approximately at the same time, and killing by freezing followed a schedule based on the time of application. Freeze drying, mounting and autographing were carried out as described above.

Results. It is important in the design of an experiment such as this to select chains of plants in which the mother-plant is fully grown, but having the two daughter plants young and dependent on the mother plant for assimilates. This was evident from the poor movement of amitrol found in tests with chains where the first daughter plant was so well developed that it was almost entirely independent of the mother plant. The consequences were, that very little food was translocated from the treated plant (mother plant) to the daughter plants, and very little of the labeled herbicide moved to the second and third plants.

This time series showed an increasing amount of translocation of amitrol, starting from the half hour treatment, where only penetration occurred. Both upward and downward movements took place in the treated leaf in the 1 hour treatment increasing in the 2 hour treatment where the chemical reached the farthest root tip (just in traces). Heavy accumulations were present in a few of the root tips where 2½ hours time had been allowed; also, although not so well defined, in the 3 and 3½ hour treatments. Apparently because of the variability among the plants the longer times including the 4 hour treatment showed much less translocation than the 2 and 2½ hour series.

This experiment confirmed the fact that amitrol tends definitely to accumulate in the meristematic tissues such as the root tips, branch roots and sprouts, following a path analogous to that described by Shaw and Samborski (17). But it has been observed that a definite accumulation in all of the active meristematic tissues becomes evident only 2 days or more after the treatments (see Figure 2), apparently because of a relatively slow penetration. In the short time treatments tested in this experiment, only the root tips showed the accumulation of a heavy amount of the labeled chemical as indicated by the autographs. Only faint images were indicated at the position of the sprouts.

B. Time series serving as comparative tests on labeled amitrol, 2,4–D, 2,4,5–T (2,4,5–trichlorophenoxyacetic acid) and MH (1,2–dihydropyridazine–3,6–dione), to determine their relative movement in the plant.

All four herbicides were labeled as follows: Amitrol had a C^{14} atom on the 5-position; both phenoxyacetic acids had the C^{14} atom in the carboxyl group, and MH had the C^{14} atom in the 5-position.

For this time series the plants were grown and treated as in the

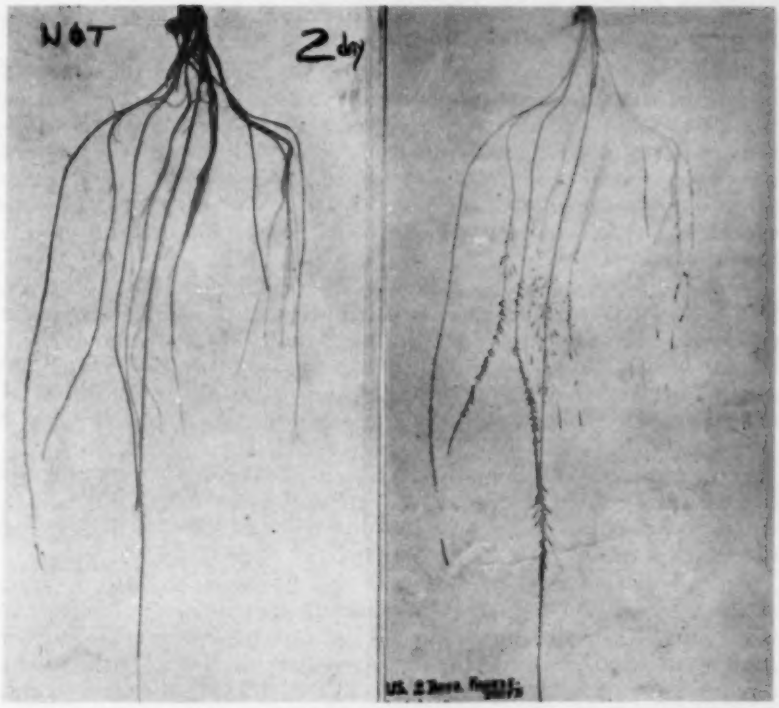

Figure 2. Autoradiograph of the basal corm and roots of a nut grass plant killed by freezing and freeze-dried 2 days after the application. Dosage 0.01 ml. of a 1% amitrol solution carrying 0.5 μc. radioactivity. Left, photograph of the plant; right, the autoradiograph.

preceding test, except that only 1 drop (10 microliters with 0.5 μc. activity) was applied per plant. A factorial time series was scheduled; 1, 5, 25, and 125 hours were the treatment times for each of the four chemicals on the nut grass plants. The total number of treatments added up to 16, and no replication was made.

Results. The 1 hour treatment showed appreciable amounts of penetration for all four chemicals; furthermore, in the case of amitrol and MH, some of the chemical already had moved out of the treated leaf. The 5 hour treatment was essentially analogous to that above, except that the autographs now indicated radioactivity in most of the fast-growing roots (especially in the tips) both for amitrol and also for MH which in addition showed trace amounts in the entire inflorescence. 2,4–D and 2,4,5–T, on the other hand, produced only very faint images of the young shoot. The 25 hour treatment presented the following picture. For amitrol the treated leaf showed radioactivity in its entire extension; most roots indicated some accumulation down to their tips, and the inflorescence had trace amounts of the chemical up to the highest point. The same occurred for MH. 2,4–D, however, did not move beyond the base of the

treated leaf, except for a very faint autograph of some of the roots, and the same was observed for 2,4,5–T.

Finally, the 125 hour series indicated that both amitrol and MH had been distributed throughout the whole plant; accumulating heavily in the treated leaf, inflorescence and all shoots, also very heavily in most roots, with medium accumulations in the mature leaves (see Figure 3 and 4). Meanwhile 2,4–D and 2,4,5–T did not cause much more than a complete distribution in the treated leaf, except for trace amounts in the roots, young shoots and in the inflorescence.

From what was described above it is evident that the autographs indicated a marked difference in distribution of the radioactive material between amitrol and MH on one hand and 2,4–D and 2,4,5–T on the other. Both amitrol and MH proved to translocate and accumulate very readily in the nut grass plant, as can be noted on the comparative photographs of the 125 hour treatments (Figures 3 and 4).

Day[2] and Crafts (4) demonstrated that 2,4–D penetrates and translocates quite readily in the leaf and stem of bean plants. But, apparently that does not happen in the nut grass, at least with regard to the translocation.

Gallup and Gustafson (8) found the monocots to absorb radioactive 2,4–dichloro–5–iodo^{131}–phenoxyacetic acid more slowly than the dicots. Translocation was also less rapid in monocots and the authors postulated a block in the intercalary meristem of the monocot leaves. Anatomically such block has not been demonstrated according to Crafts (3).

Eames (6) made anatomical studies of the effect of some formulations of 2,4–D on *Cyperus rotundus* and he stated that most of the internal modifications found in this monocotyledonous plant are similar to those found in the dicotyledonous bean plant; that tissues such as those in stems become highly meristematic, forming abnormal tissues continuously for some time. A year later, Eames (7) reported studies on the destruction of phloem in young bean plants after treatment with 2,4–D.

This brief study of translocation of two phenoxyacetic acids as compared with amitrol and MH leaves the impression that something is hindering the phenoxyacetic acids from translocating as readily in the nut grass as described by Day[2] and Crafts (4) for bean plants. One cause of this difference may easily be the much higher concentration employed here, as compared with what was used by Day in his research. The concentration of 2,4–D applied here, 22,100 ppm equals 0.1M, against 500 ppm used by Day; in both cases a droplet of 10 microliter volume was applied. Eames (7) sprayed with a 125 ppm solution of 2,4–D in carbowax, which probably resulted in the absorption of an amount more comparable to that used in Day's treatments. The rather high concentration of 2,4–D here would easily increase the possibility of phloem destruction as suggested by Eames (7). Obviously, even in its very early

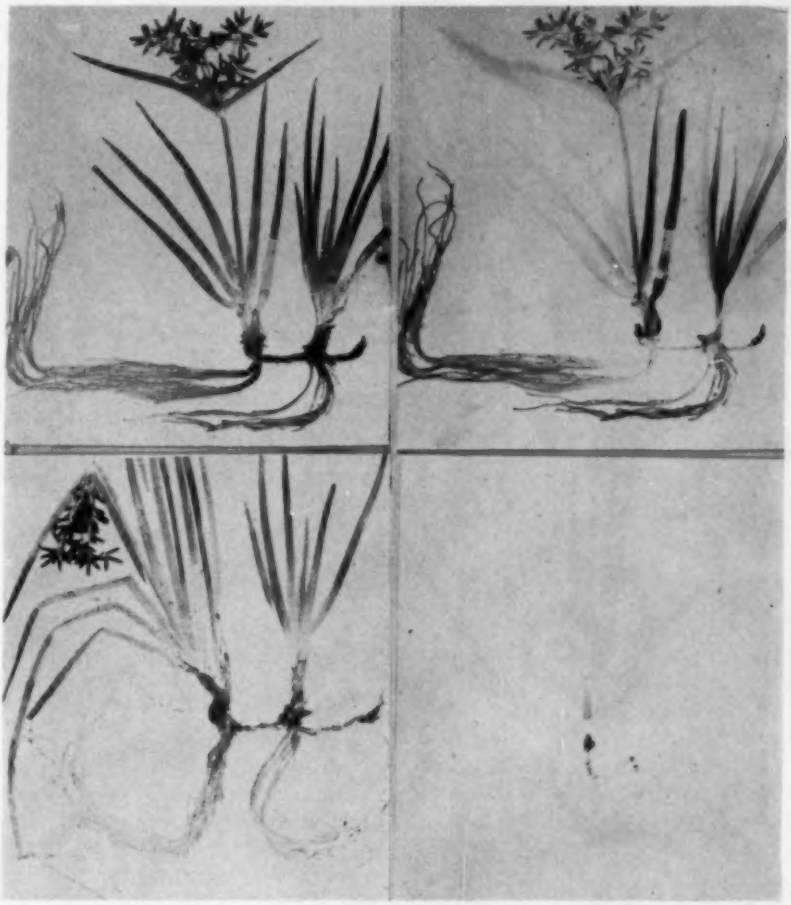

Figure 3. Photographs and autoradiographs of chains of nut grass plants killed by freezing and freeze-dried 5 days after the application. Dosage 0.01 ml. of a 0.1 M solution of the chemical carrying 0.5 μc. radioactivity. Left, photographs of the plants; right, the autoradiographs. Upper, photograph and autoradiograph for amitrol; lower, photograph and autoradiograph for 2,4–D.

phase, the effect would in turn reduce the translocation of the herbicide.

Still another possibility should be considered; Weintraub *et al.* (20), Hay and Thimann (10) and others claim to have evidence for a fairly rapid metabolism of 2,4–D in plants. If this occurs shortly after the application, it certainly would change the interpretation of the autographs described above. It seems obvious that the simple detachment of the radioactive side-chain from the 2,4–D molecule would result in failure of the different points of accumulation of the ring-structure to autograph, since it may be presupposed that the radioactive part has moved elsewhere.

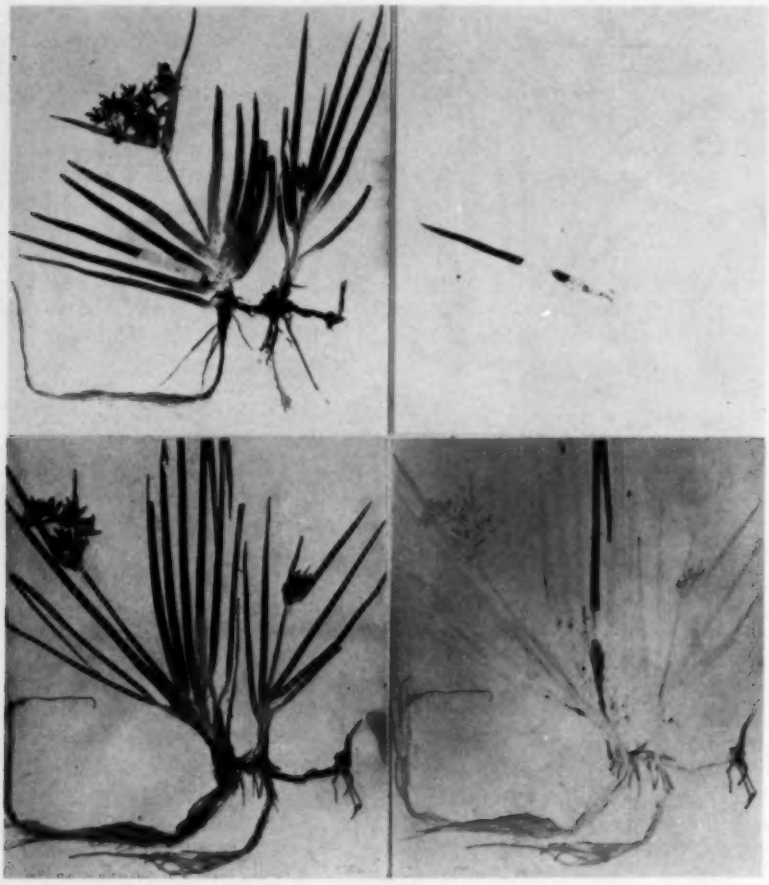

Figure 4. Photographs and autoradiographs of chains of nut grass plants killed by freezing and freeze-dried 5 days after the application. Dosage 0.01 ml. of a 0.1 M solution of the chemical carrying 0.5 μc. radioactivity. Left, photographs of the plants; right, the autoradiographs. Upper, photograph and autoradiograph for 2,4,5–T; lower, photograph and autoradiograph for MH.

In the interpretation of the results above, it is important to take into consideration the fact that both amitrol and MH were labeled with C^{14} firmly attached in the ring structure while in the 2,4–D and 2,4,5–T used the C^{14} was in the more labile side chain.

This second time series also served to complete the first series for amitrol, giving an idea of the translocation and accumulation of this herbicide after 5, 25 and 125 hours.

No definite translocation boundary was observed in the autoradiographs for these time series, and no definite accumulation of amitrol in growing points could be detected in the short time series,

because no substantial proportion of the radioactive material had had time to be absorbed. This would indicate that the translocation is so much faster than the penetration that this latter may be considered definitely as the limiting factor in the process involving the distribution of the herbicide from the surface of the leaf into the plant system. This is in agreement with Day[2] who determined the rates for the absorption and translocation of 2,4–D in bean plants. He calculated that the absorption involves migration in parenchyma that occurs at an average linear rate of 30 microns per hour, while translocation in the phloem reaches speeds between 10 and 100 cm. per hour.

II. SITES OF ACCUMULATION OF AMITROL IN THE TUBERS OF THE NUT GRASS FROM APPLICATION ON THE LEAF.

As emphasized before, a very important property required of a herbicide intended for the successful control of nut grass, is that it be readily translocated down to the tuber to destroy the viability of these organs.

The scarcity of information about the mobility of amitrol to the tubers and the pattern of its distribution in these organs, suggested the following test.

Nut grass plants were raised from tubers in sand culture. Plants that produced two tubers or more were transplanted individually to No. 10 cans with a 2 inch layer of sand on the bottom and over that, 4 inches of vermiculite. The plants were placed in such a way that the roots were mostly in the sand and the tubers in the vermiculite. Sub-irrigation was applied. All this was done to avoid sprouting of the tubers before the treatment.

Two weeks after transplanting, the plants were treated with radioactive amitrol as described. One plant received two drops (1.0 μc. activity), two other plants received one drop each (0.5 μc. activity). The plants were then left for 4 days for the translocation of the labeled chemical to the tubers. Then the plants were removed from the sand and vermiculite, washed clean from these materials and the tubers were removed one by one and sliced (1 to 1.5 mm. thick). The slices were glued with starch glue to a single sheet of lithograph paper in the sequence in which they were prepared.

As soon as all the material had been mounted, it was frozen and placed in the vacuum tank to freeze-dry. After 4 days the mounts were pressed and placed on the X-ray film; after 4 weeks the film was developed.

Results. The photographs (Figure 5) confirm once more what has been observed with respect to amitrol in the tissues of nut grass plants: it translocates readily into all of the active tissues and is very definitely accumulated in the meristems, such as active buds, sprouts, root tips, etc. It is scarce or lacking in dormant buds, storage parenchyma, and mature tissues in general.

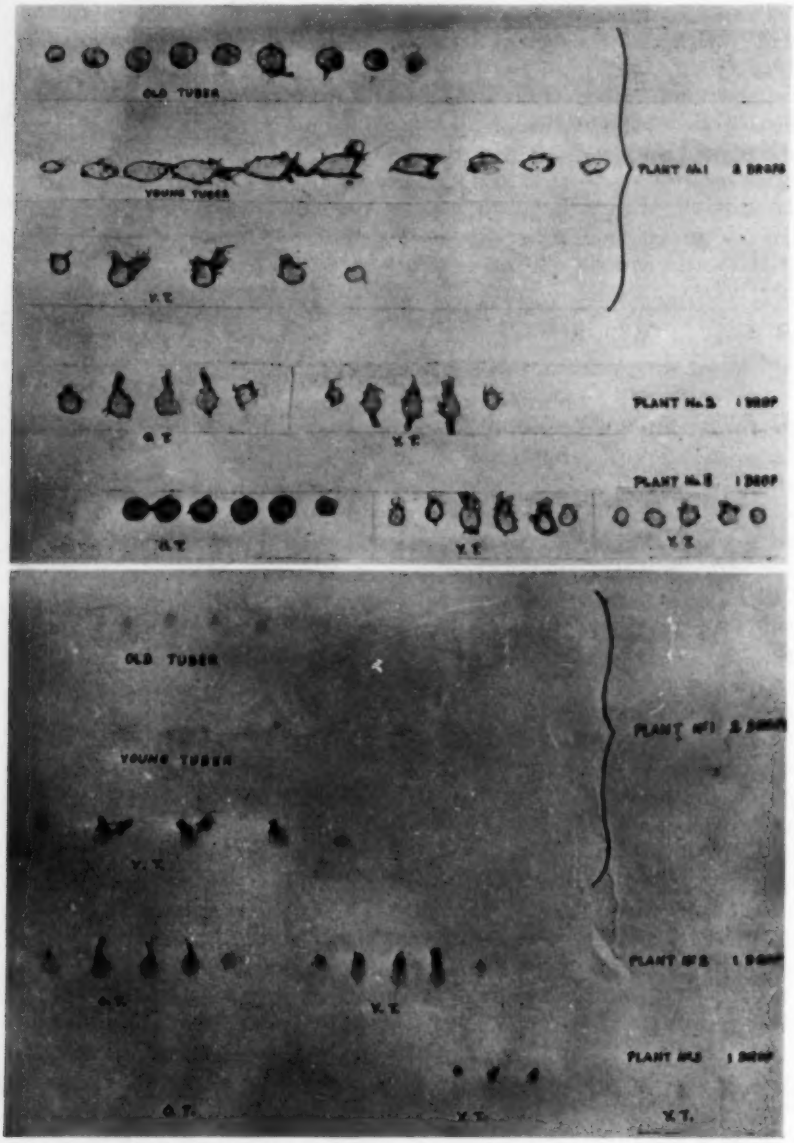

Figure 5. Photograph and autoradiograph of tubers from nut grass plants treated with two drops (0.02 ml. with 1.0 μc. activity) or one drop of amitrol (0.01 ml. with 0.5 μc. activity). Tubers were removed, sliced, killed by freezing and freeze-dried on the fourth day after treatment. Upper, photograph of the tuber slices; lower, autoradiograph produced by the tuber slices.

III. THE RESPONSE TO VARIABLE CONDITIONS OF ILLUMINATION AS AN INDICATION OF THE MECHANISM FOR THE MOVEMENT OF AMITROL IN THE NUT GRASS PLANT.

According to van Overbeek (15), "the translocation of plant regulators follows a pattern similar to that of most other organic compounds. When a compound is taken up by the roots, transport upward into the aerial portion of the plant takes place through the xylem, while in general, one may say that if a compound is taken up by the leaves, it is transported out of that leaf via the phloem."

The topic which presently will be focalized is the effect of carbohydrates on the translocation of plant regulators. Mitchell and Brown (14) on the basis of their experimental results stated that the movement of 2,4–D does not take place out of the leaves which are low in carbohydrates. Rohrbaugh and Rice (16) working with 2,4–D on bean seedlings kept in the dark until carbohydrates were depleted, added the conclusion that, when sugars were supplied either through photosynthesis (by illumination) or through sugar application, the translocation of 2,4–D was restored in the depleted plants. The general conclusions above were later confirmed by Weintraub and Brown (20), Jaworski, Fang and Freed (12), and others.

Wanting to test whether amitrol, when applied on the leaf of nut grass, followed the general pattern described above, the following experiment was designed. The nut grass plants were grown in quart-size Mason jars (one plant per jar) to the six to eight leaf stage. These plants were then placed in complete darkness and leaves sampled for starch every day by using a test described by Weier, Stocking and Tucker (19). After 3 days no more starch was detected in the leaves, so eight of the remaining plants which had not suffered removal of leaves were treated with radioactive amitrol as described for the other experiments. One drop having 0.5 μc. activity was applied per plant. The eight plants were then subjected to 4 different conditions (two replicates in each): four plants returned to complete darkness for the additional 3 days the experiment lasted, with two of the plants having the treated leaf dipped in 0.1 M (18%) glucose solution almost up to the point of treatment; two other plants were placed in the light, but each had the treated leaf covered by black paper to maintain complete darkness: finally, the last two plants were placed in a well sealed unlighted cardbox, having only the treated leaf reaching out to the light through a narrow hole. After 3 days all plants were killed by freezing and treated as described before.

Results. The photographs in Figures 6 and 7 show the results obtained. The plants which continued in the dark after the treatment and did not have glucose supplied on the upper part of the treated leaf showed some translocation of the labeled amitrol (traces) to most of the plant parts. It is probable that some sugars

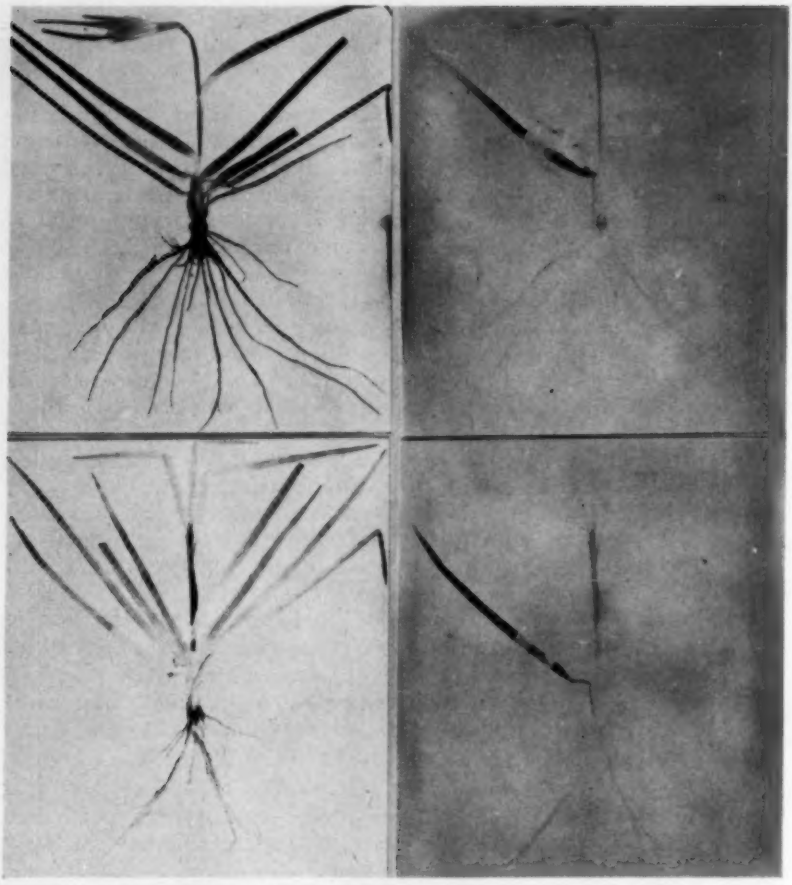

Figure 6. Photographs and autoradiographs of nut grass plants which were depleted of starch, treated with one droplet of amitrol (0.01 ml. with 0.5 μc. activity) and maintained for 3 days under variable conditions of illumination before they were killed by freezing and freeze-dried. Left, photographs of the plants; right, the autoradiographs of the plants. Upper, the treated plant continued in darkness; lower, treated plant continued in darkness with the tip of the treated leaf dipped in a 0.1 M glucose.

had still been present in the treated leaf at the time of treatment, although no starch had been detected.

On the other hand, the glucose treatment did not make much difference in the translocation of the amitrol. Probably only a very minute amount of this sugar was absorbed.

In the two last treatments, however, very striking and opposite effects were evident in the autographs. The plant which had the treated leaf kept in darkness, while the rest of the plant was placed in the light did not have any of the radioactive amitrol moved out of the leaf; on the contrary, it looked as if the movement of food into

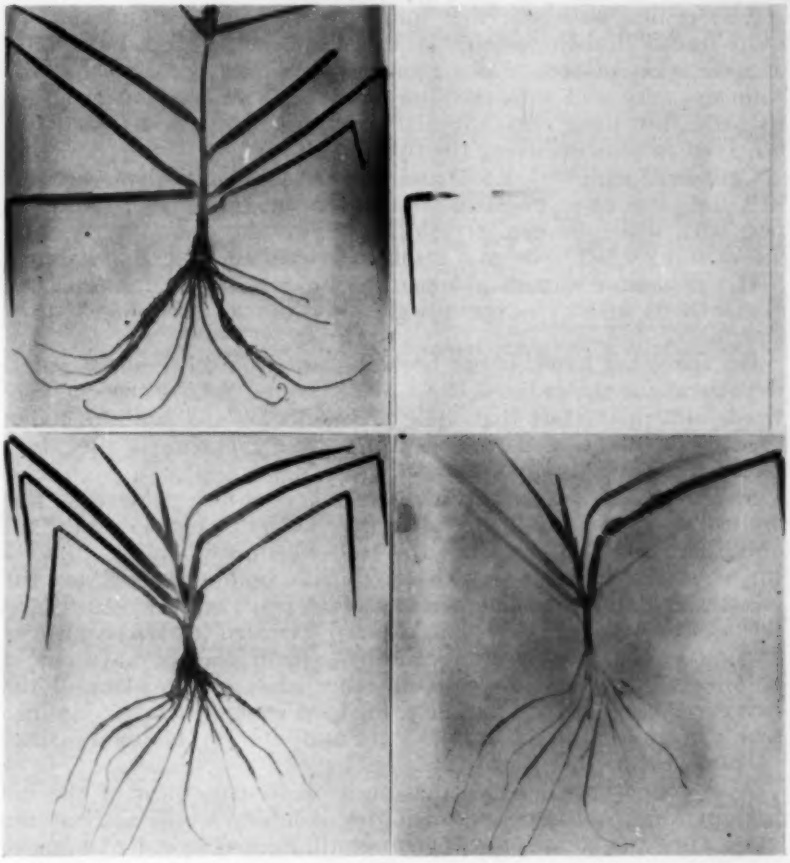

Figure 7. Photographs and autoradiographs of nut grass plants which were depleted of starch, treated with one droplet of amitrol (0.1 ml. with 0.5 μc. activity) and maintained for 3 days under variable conditions of illumination before they were killed by freezing and freeze-dried. Left, photographs of the plants; right, autoradiographs of the plants. Upper, the treated leaf continued in darkness with the rest of the plant in light; lower, the treated leaf exposed to light with the rest of the plant in darkness.

the leaf from the other part of the plant had pushed the chemical further toward the tip of the leaf, away from its base. The plant which had only the treated leaf in the light had the radioactive herbicide rapidly moved out of the treated leaf and distributed all through the plant.

This experiment shows, in a conclusive way, that amitrol moves in the nut grass plant together with the photosynthetic food stream, agreeing with former works on translocation of plant regulators.

SUMMARY AND CONCLUSIONS

Studies on the absorption and translocation of amitrol in the nut grass were conducted, employing the radioactive isotope.

The results indicated that amitrol penetrates and translocates quite readily in the *Cyperus;* also that this herbicide shows a definite accumulation pattern at the growing points, an occurrence which coincides very well with the sites where amitrol is found to attain its maximum toxic effect. Similar accumulation patterns were also observed in tests involving the tubers.

Compared with MH, 2,4–D and 2,4,5–T, the superiority of amitrol in killing this complex plant system seems to result from the readiness with which amitrol translocates to all the plant parts, while 2,4–D and 2,4,5–T showed a rather restricted translocation pattern. MH was similar to amitrol regarding its ease of translocation, but evidently its toxicity to the nut grass was much lower than that of amitrol.

On the other hand, it has been suggested by other authors that the reason for the reduced effect of 2,4–D and 2,4,5–T on complex weeds, lies in the fact that these herbicides are frequently metabolized by the plant, rendering them inactive rather shortly after their penetration into the plant system.

Starch-depleted plants which received one drop of radioactive amitrol on the leaf and thereafter were kept in variable conditions of illumination, showed that the translocation of amitrol follows the stream of the photosynthates, as has been described for the growth-regulators by some workers. This was clearly evidenced by the results, which showed that, when the treated leaf received light enough for its photosynthesis, amitrol would readily move out of that leaf and spread over all the other parts of the plant. If the treated leaf was kept in darkness, the food stream then moving into that leaf would push the herbicide the opposite way, taking it further back toward its tip.

As a conclusion it seems that amitrol presents most of the important qualities necessary to destroy complex weeds such as the nut grasses, but some improvement is still needed in order to render it economical.

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The Effect of Surfactants on Foliar Absorption of 3–Amino–1,2,4–triazole [1, 2]

V. H. Freed and Marvin Montgomery

The biological effectiveness of any systemic herbicide is vitally dependent upon the absorption of the chemical by the plant. The process of absorption is of particular interest in the use of herbicides and it is only as this process is understood and turned to advantage that maximum effectiveness of applied chemical can be achieved. In foliar absorption, with which this paper is concerned, the cuticle plays a very important role (2). The thickness and general state of the cuticle and the attendant stomata have been shown to vary markedly with growth conditions (10). The submicroscopic structure of cuticles and the accretion of wax deposit on leaf surfaces have been studied (7, 8). These factors are of significance in the consideration of the intimacy of the contact of a particle impinging on the leaf. The chemical nature of the cuticle (6) is undoubtedly of great importance in the partitioning of certain herbicides between a particle of the chemical and the interior of this leaf.

If one pictures the problem of absorption as a rate process, then the concept of an energy barrier to this rate process is brought into consideration (2). In such a case, the absorption rate should be dependent–within limits on the area of exposure, on the concentration of the chemical and on the condition of the "energy barrier" as represented physically by the cuticle and its stomata (1, 3). It has been shown (4, 5) that additives, such as surfactants can appreciably increase the absorption of herbicides. It may be due to a more intimate contact of the droplet with the cuticle or a better penetration into the stomata if this is the region of absorption as suggested by Skoss (10). However, it has been shown that other agents, notably glycerin (5, 9), can have a profound influence on the permeability of the cuticle. These agents could only be construed as in some manner reducing the "energy barrier" in the absorption process.

The work to be reported herein was concerned with the influence of surfactants of the penetration of amitrol. The object of the study was to ascertain whether or not there is a molecular interaction between the surface active agent and the herbicide being absorbed, reducing the height of the energy barrier.

Materials and Methods

3–Amino–1,2,4–triazole (amitrol) was selected for study in part because of its importance as a herbicide, its absorption behavior and ease of determination and because of certain of its chemical prop-

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erties. The plants employed in the study were Black Valentine beans grown under greenhouse conditions.

Preliminary studies indicated that amitrol applied to bean leaves could be recovered quantitatively by washing the leaves with an adequate quantity of water. In this study, the desired amount of chemical was applied as 0.1 milliliter droplets to the leaves with a micro syringe. Treatments were made to one leaf per plant after the primary leaves were fully expanded. The solution containing 250 micrograms of the chemical in 0.1 milliliter was applied to the leaf. The desired concentration of surfactant was mixed with the chemical solution prior to application. Determinations of pH and surface tension were then made on these solutions. A Beckman Model G pH meter was used to determine pH. Surface tension was measured with either a DuNuoy tensiometer or a stalagmometer.

For purposes of this study, surfactants of the alkylaryl sulfonate type and the alkylaryl polyoxyethelene glycol type were used as representing the more common surfactants.[3]

Following the treatment, the leaves were harvested at desired time intervals and washed well with a fine stream of distilled water. The washings were then analyzed for amitrol by the method of Sund (11). Samples were taken at zero time, that is, immediately following treatment, and the analyses carried out as described. This gave the original amount of material applied to the leaf so that the difference between the original amount and that found at subsequent time intervals was assumed to represent the portion of material absorbed by the plant.

RESULTS AND DISCUSSION

The first experiment consisted of following the absorption of the amitrol from solution on a bean leaf with and without a surfactant. Each treatment was made in triplicate. Table 1 presents the average results obtained in this trial.

Table 1. The time-course of absorption of amitrol as influenced by a surfactant.

Solution	Surface tension (dynes/cm)	pH	Pct. applied amitrol absorbed		
			21 hrs.	93 hrs.	117 hrs.
Amitrol alone	69.6	5.87	11.3	13.0	55.4
Amitrol + 0.1% v/v X-77	33.3	5.82	27.5	43.5	87.3

It is very evident from the data in the table that the surfactant had a marked influence on the rate and amount of chemical absorbed. Inasmuch as it is very common to compare surfactants by measurement of surface tension, the question arose whether or not lowering of surface tension *per se* would bring about a proportional increas-

[3]Supplied by Colloidal Products Company. Designations as follows:
Multifilm C—alkylaryl polyoxyethylene glycol in petroleum oil
Multifilm L—petroleum sulfonates in petroleum oil
X-77—alkylaryl polyoxyethelene glycol in isopropanol.

ing absorption. The second experiment was designed to test the effect of different surfactants at the same concentration. Again, pH and surface tension of the solutions were determined before the application. Table 2 summarizes the results of this experiment with the data representing an average of triplicate measurements.

Table 2. The effect of different surfactants on the foliar absorption of amitrol.

Solution	Surface tension (dynes/cm)	pH	Pct. applied amitrol absorbed	
			24 hrs.	48 hrs.
Amitrol	69.6	5.87	13.1	
Amitrol + Mult. C 0.05% V/V	50.3	5.90	18.8	41.7
Amitrol + Mult. L 0.05%	59.1	6.40	25.5	
Amitrol + X-77 0.05%	33.3	5.82	77.8	81.8

It will be noted in Table 2 that the surfactant giving the lowest surface tension did indeed show the greatest amount of absorption, but the fact that the surfactant giving the smallest reduction in surface tension resulted in an absorption greater than the one which was approximately 20% lower, suggests that there is an interplay between the surfactant and the molecule being absorbed.

In the third experiment of this series, the herbicide solution containing the surfactant was made up to have a surface tension of 49 ± 2 dynes/centimeter. In this case, it was found necessary to vary the concentration of the individual surfactant within wide limits in order to achieve the desired surface tension. It will be noted that in one case, .013% surfactant was sufficient to give a surface tension of 50.9 dynes/centimeter, whereas in another case, 0.5% was required to give the desired surface tension. Table 3 presents the information obtained in this study as an average of three determinations.

Table 3. The effect of different surfactants at the same surface tension on foliar absorption of amitrol.

Solution	Surface tension (dynes/cm)	Pct. amitrol absorbed 24 hrs.
Amitrol	69.6	12.2
Amitrol + Mult. C (.1%)	49.8	16.7
Amitrol + Mult. L (.5%)	47.5	37.2
Amitrol + X-77 (.013%)	50.9	51.0

The data of Table 3 give a very clear demonstration of the interrelationship of the surfactant with the herbicide in the absorption process. Even though here the most effective surfactant is at a concentration of several orders of magnitude less than the other, it still brings about the most absorption of amitrol. One could account for this only on the basis of a molecular interaction between the herbicide and the surfactant.

It is thought probable that the action of the surfactants involves not only a matter of intimacy of contact of the spray droplet with

the plant's surface but maintaining the herbicide in a fluid state as the aqueous carrier evaporates as well as the direct effect of the surfactant on the plant's surface and/or the underlying tissue.

SUMMARY AND CONCLUSION

A study of the influence of surface agents on the absorption of amitrol by bean plants was made. Absorption was followed by removal of the residue on the leaf and analyses of this solution. The data presented suggest that: (a) reduction of surface tension is an important factor in absorption and translocation, but (b) the relationship of molecular interaction between the surfactant and the herbicide is of perhaps equal or more importance than that of lowering of surface tension. (c) There is some indication of highly specific requirements for surfactant formulation to fit the herbicide in order to achieve maximum effectiveness.

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A New Method for Evaluating Potential Algicides and Determination of the Algicidal Properties of Several Substituted-urea and *s*-Triazine Compounds

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A RELATIVELY simple method for screening and evaluating chemicals for algicidal properties has been developed which embodies spray application of chemicals and greenhouse culture conditions. The method utilizes equipment and facilities common to the majority of industrial herbicide screening programs.

Extensive testing of chemicals as algicides has been conducted at the University of Wisconsin (3) and at the Robert A. Taft Sanitary Engineering Center, Cincinnati (6, 7, 8). At both institutions the screening methods have involved growth of pure cultures of various species of algae in liquid nutrient media under constant temperatures and artificial illumination. Other investigating laboratories have employed similar techniques (10, 12). However, the total number of chemicals screened under these conditions is probably of the order of 500, a rather small figure considering that nearly ten thousand new chemicals are synthesized and screened annually for other types of biological activity. Limited testing of antibiotics against algae has been accomplished by adapting techniques commonly employed in bactericidal and fungicidal screening (4).

The present studies and development of the method have been founded on field observations that certain soil-borne algae could be controlled by 1–*n*–butyl–3–(3,4–dichlorophenyl)–1–methylurea (neburon). Four substituted-urea herbicides have subsequently been evaluated for their algicidal properties in comparison with other commonly used algicides. Three of these compounds previously have been shown to decrease photosynthesis in higher plants by inhibition of the Hill reaction (11). The recent finding that 2–chloro–4,6–bis (ethylamino)–*s*–triazine (simazin) is also a potent inhibitor of the Hill reaction[2] prompted an evaluation of several *s*–triazine derivatives by this method.

MATERIALS AND METHODS

Nutrients and substrate. The present method has been designed for linear measurement of the surface growth of algal cultures on nutrient-moistened solid substrates. In previous work involving nutrient culture of higher plants in a perlite medium, prolific surface growth of algae had been noted frequently following applications of nutrient solutions. Nutrient-perlite media were therefore selected for this work.

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[2]Personal communication from D. E. Moreland, Plant Physiologist, Crops Research Division, ARS, N.C. State College, Raleigh, N.C., July, 1957.

Five-ounce paper cups were filled with a fine grade of perlite, which is available commercially for use as a plaster ingredient. This material has no measurable base-exchange capacity and is essentially inert chemically. It provides a firm, smooth surface when saturated. The cups of perlite average about 25 g when dry, and 75 ml of solution will bring the perlite to saturation. The total weight of approximately 100 g for the freshly prepared cups has been found convenient for calculating moisture losses during the course of experiments.

Quarter-strength Shive's nutrient solution (2) and a slightly modified Bonner's salt solution (1) have been employed with equally satisfactory results. Stock concentrates of nutrient were prepared and diluted as needed with tap water; hence, no minor element supplements were considered necessary. (Note: Use of highly chlorinated tap water for dilutions was avoided.) Some of the nutrients usually have precipitated in stock concentrates of Shive's nutrient; Bonner's salt concentrates are more stable. Other investigators have frequently employed Gerloff's modification of Chu No. 10 nutrient (5).

Inoculations. For each experiment algal growths were collected from potted rice cultures or from greenhouse soil surfaces and were suspended in a suitable volume of tap water. After vigorous agitation, the suspension was strained through 2 or 3 layers of cheesecloth to remove larger aggregations and surface scums. The strainings were then centrifuged for 5 minutes at a low speed to remove heavier particles. The lighter material, which constituted the supernatant, was decanted and recentrifuged at higher speeds for a sufficient length of time to produce a soft pellet. The pelleted algae were resuspended in a small volume of nutrient solution to produce the final inoculum. One drop was then added at the center of each cup of nutrient-perlite medium by means of a dropping pipette. Chemical applications were made immediately after inoculation or after a 16 to 20 hour period of growth adjustment in the greenhouse.

Microscopic examination was made of each inoculum to determine its botanical composition at the time of use.

Chemical applications. All chemicals, as listed in Table 1, were formulated in 100 ml of water. Each chemical treatment was formulated separately and applied by spray at the rate of 40 gal/A using an 8003–E Tee-Jet nozzle on the endless-belt spray table described by Shaw and Swanson (9). Application rates ranged from 1/64 to 1 lb/acre. (The 1 lb/acre rate of application deposited 0.3 mg of a chemical per cup. This amount of chemical in 75 ml of solution produces a concentration of 4 ppmw. By other approximations the 1 lb/acre rate corresponds closely to an application of 11.5 lb/acre-foot on open waters.)

Culture conditions. After spraying, all cups were placed at random in metal flats containing sand. These flats in turn were placed in the greenhouse on large bench trays filled with gravel. In order to provide for high relative humidities and reduce evaporation from the cups, the trays were filled with sufficient water to cover the gravel and

Table 1. Chemicals and formulations evaluated for algicidal properties by the nutrient-perlite method.

Chemical name	Abbreviation or common name	Grade or formulation
Cupric ion	Copper (ionic)	$CuSO_4 .5 H_2O$, reagent (25% Cu^{+2})
Isopropyl N-(3-chlorophenyl)carbamate	CIPC	Commercial, 4 lb/gal
2,3-Dichloro-4-naphthoquinone	Dichlone	Commercial, 50% W.P.[a]
3-Phenyl-1,1-dimethylurea	Fenuron	80% W.P.
3-(*p*-Chlorophenyl)-1,1-dimethylurea	Monuron	80% W.P.
3-(3,4-Dichlorophenyl)-1,1-dimethylurea	Diuron	80% W.P.
1-*n*-Butyl-3-(3,4-dichlorophenyl)-1-methylurea	Neburon	80% W.P.
2-Chloro-4,6-bis(diethylamino)-*s*-triazine	CDT	49.5% W.P.
2-Chloro-4,6-bis(ethylamino)-*s*-triazine	Simazin	50% W.P.
2-Chloro-4,6-bis(isopropylamino)-*s*-triazine		50% W.P.
2-Chloro-4-diethylamino-6-isopropylamino-*s*-triazine		50% E.C.[b]
2-Chloro-4-ethylamino-6-diethylamino-*s*-triazine		50% W.P.
2-Chloro-4-*n*-propylamino-6-isopropylamino-*s*-triazine		50% W.P.
2-Methoxy-4,6-bis(ethylamino)-*s*-triazine		50% W.P.

[a]W.P.—Wettable powder
[b]E.C.—Emulsifiable concentrate

insure that the sand in the bottoms of the flats remained constantly moist. Three cups were selected at random at two- to three-day intervals and weighed. On the assumption that evaporative water loss was equal in all cups, sufficient water was replaced in each cup to return it to saturation, using the calculated loss of 100 g minus av. wt. of 3 cups.

The three experiments reported herein were conducted in the greenhouse during the months of August and November, 1956, and August, 1957. Ordinary greenhouse temperature and light conditions prevailed during these periods. Thermostatically controlled heating maintained a 70° F minimum temperature during cold weather, and ¾-stripe whitewash was used to reduce heating during the summer months. Maximum temperatures, which occurred in August, 1956, ranged to 110° F.

Methods of evaluation. Development of algal colonies proceeded in a more or less circular pattern from the inoculated center. In most instances growth was confined to the upper 2 to 3 mm of the perlite, presumably because of light relationships. Cultures were allowed to develop until the colonies on untreated check cups reached the periphery of the perlite surface. Two linear measurements were then made of all colonies. The average of these two measurements, the longest and shortest dimensions, was recorded as the mean diameter of the colony. Since two circular areas are proportional to the squares of their diameters, comparative expression of relationships was obtained by the formula

$$\frac{d^2_o - d^2_t}{d^2_o} \times 100 = \text{percent growth inhibition}$$

where d_o and d_t are the diameters of the colonies on untreated and treated cups, respectively.

The experimental design in the present work was a randomized block with three replications. In order to test for validity of the method, inhibition percentages were calculated in each replication and results were subjected to an analysis of variance. Experience has shown, however, that the inhibition percentages can be calculated more expediently from the mean diameters for each treatment with but slight resultant error.

RESULTS AND DISCUSSION

The results of microscopic examinations of inocula showed considerable variation in composition. Tentative identification was made of dominant forms of algae present. In Experiment I the inoculum consisted of an almost pure culture of *Chlamydomonas,* collected from rice pots. The inoculum of the second experiment contained predominantly a filamentous *Hormisceum* and a species of *Protococcus;* that of the third experiment had in addition another filamentous green alga, a small amount of the blue-green *Oscillatoria,* and several motile unicellular organisms. The time required for

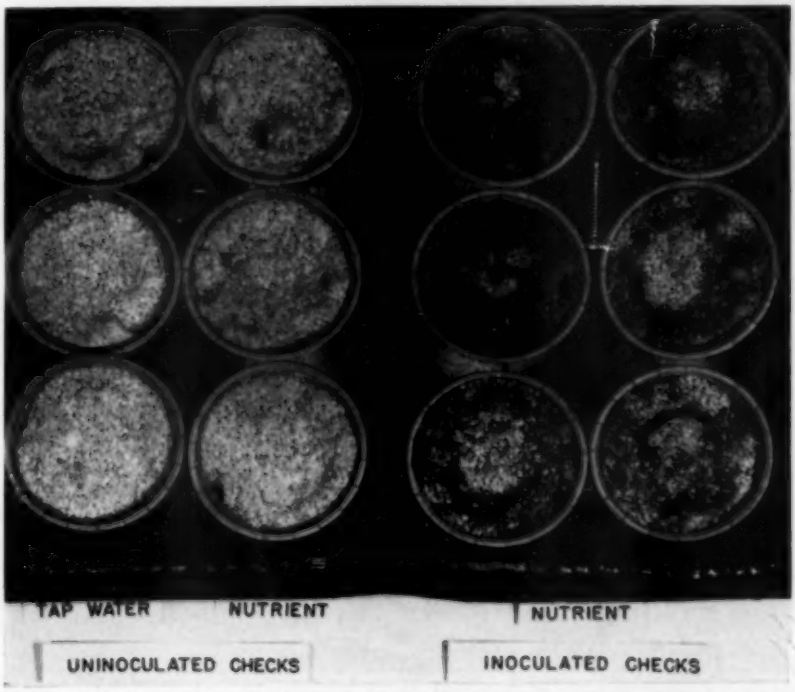

Figure 1. Characteristic development of algal colonies on nutrient-moistened perlite in paper cups. Uninoculated cups at left served as contamination checks. One spot contamination, not centered, is seen in second cup at top. Colonies on inoculated checks (right) frequently show central bleaching with age. Peripheral disturbances of the perlite are sites of water additions. Expt. I.

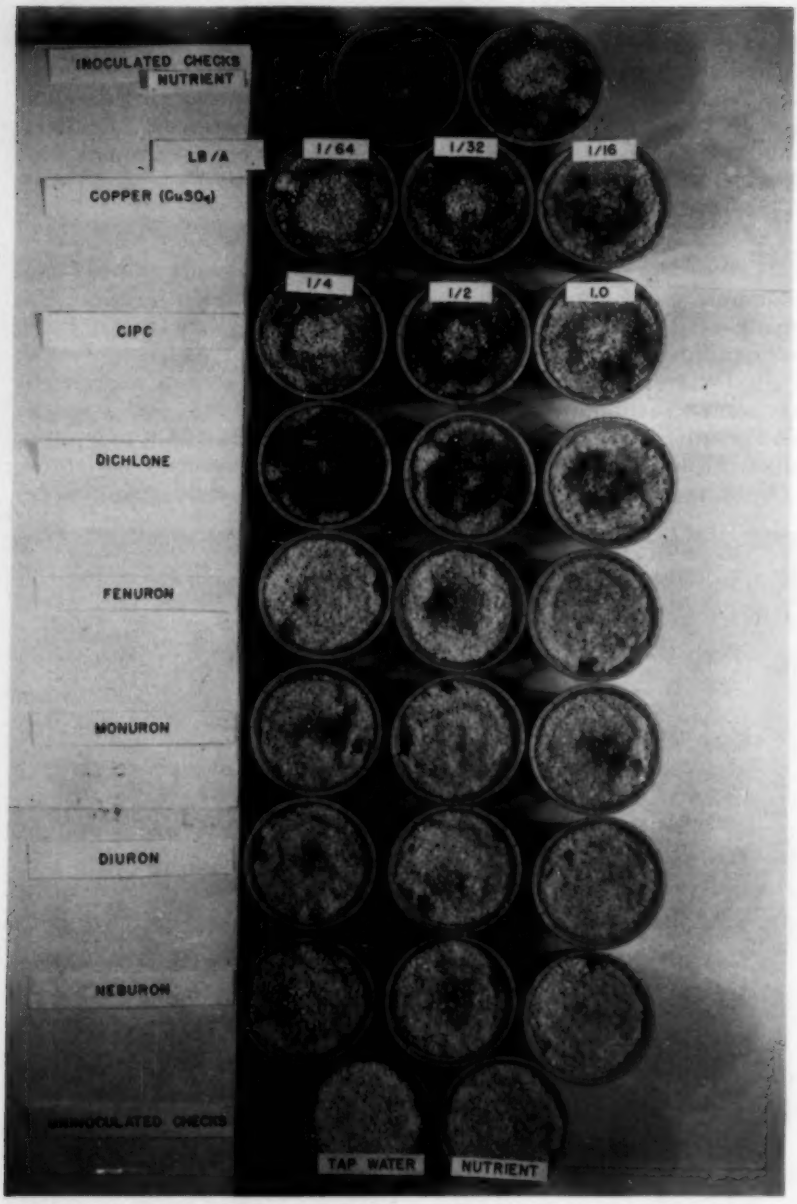

Figure 2. Inhibition of algal growth by various chemicals at three rates each. Expt. I

these cultures to spread over the entire surface of inoculated check cups also varied, being 14, 28, and 9 days in Experiments I, II, and III, respectively. Although direct comparisons of various chemical treatments between experiments may not be warranted because of botanical and time variations, all data have been summarily presented in Table 2 for convenience. Figures 1 and 2 illustrate various points of technique involved.

In Figure 1 the characteristic type of growth obtained in inoculated cups is shown along with uninoculated cups which were included to determine the influence of chance contaminations upon results. Few such contaminations were observed. In general these were in off-center positions and occupied no more than 5% of the total area. In view of the rather large differences required for significance between treatments (Table 2), contaminations were considered to be of negligible importance. One of the largest sources of error appeared to result from too rapid addition of water in replacing evaporative losses. Therefore, care should be taken to prevent

Table 2. Comparison of algicidal effectiveness of 13 chemicals. Tabular values represent percentage inhibitions of algal colonial growth.

Chemical	Mean inhibition at various rates (lb/A)							Average inhibition (all rates)
	1/64	1/32	1/16	1/8	1/4	1/2	1	
Experiment I (August 1956)								
Copper (ionic)	11	16	43	—	—	—	—	23
CIPC	—	—	—	—	13	24	35	24
Dichlone	—	—	—	—	16	61	73	50
Fenuron	—	—	—	—	84	85	99	89
Monuron	—	—	—	—	95	99	97	97
Diuron	—	—	—	—	97	100	100	99
Neburon	—	—	—	—	88	84	94	89
LSD 5% level				28				19
1% level				37				25
Experiment II (November 1956)								
Copper (ionic)	—	—	86	98	100	97	100	97
Dichlone	—	—	43	47	68	45	20	45
Fenuron	—	—	51	80	90	100	100	84
Monuron	—	—	14	57	100	100	100	74
Diuron	—	—	100	83	100	100	100	97
Neburon	—	—	97	100	93	100	100	98
LSD 5% level				29				13
1% level				38				17
Experiment III (August 1957)								
Copper (ionic)	61	78	82	85	96	97	100	86
s-Triazine derivatives:								
2-Chloro-4,6-bis(ethylamino)-(simazin)	79	90	89	100	100	99	100	94
2-Methoxy-4,6-bis(ethylamino)-	54	88	93	94	99	100	100	90
2-Chloro-4,6-bis(isopropylamino)-	81	75	77	89	96	97	99	88
2-Chloro-4-*n*-propylamino-6-isopropylamino-	49	56	89	91	77	97	95	79
2-Chloro-4-ethylamino-6-diethylamino-	34	81	45	44	88	91	88	67
2-Chloro-4-diethylamino-6-isopropylamino-	14	42	38	57	74	43	54	46
LSD 5% level				25				10
1% level				34				13

streaming of water across a developing algal colony, which may result in erratic development and complicate final readings.

At the termination of an experiment the cups most closely representing the colonial development in each treatment could be selected rapidly by visual estimation or by determination of experimental means. These were arrayed for photographic recording of results. Figure 2 presents graphically some of the data reported in Table 2.

The substituted-urea herbicides demonstrated very good algicidal properties as a group. The range of concentrations used in the first experiment, however, failed to demonstrate the limits of their effectiveness. In the second experiment diuron and neburon, which have two chloro-substitutions and are the least water-soluble of the substituted-ureas used, were equally as efficient as copper in inhibiting growth at all rates employed. The more soluble compounds, fenuron and monuron, were less effective than copper ion or the two dichloro-substituted urea compounds at the 1/8 and 1/16 lb/acre rates. Further evaluation of all of these urea compounds, however, would seem to be warranted. Their application at any rate below 1/4 lb/acre would be well below a concentration of 1 ppm, which is the residue tolerance level already established for some of them on certain fruits and vegetables.

The compound simazin proved to be even more effective than copper at very low rates of application. Interesting relationships between algicidal toxicities and structural configuration were obtained by making comparisons between all of the *s*-triazine derivatives used in Experiment III. In Table 2, the compounds have been listed in order of decreasing effectiveness. Exchange of a methoxy group for the chlorine at the 2-position of simazin or of isopropyl groups for the ethyl moieties on the 4- and 6-amino nitrogen atoms had little effect on activity. The combined substitution of an isopropyl and an *n*-propyl group for the two ethyl groups of simazin, however, significantly decreased the effectiveness of the chemical at the 1/64 and 1/32 lb/A rates of application. The presence of two ethyl groups on either of the two amino nitrogen atoms also reduced algicidal toxicity, as seen in the data for the 4-diethylamino-6-isopropylamino and the 4-ethylamino-6-diethylamino derivatives. Data for 2-chloro-4,6-bis(diethylamino)-*s*-triazine (CDT) have not been included, since results for some of the rates were negated by experimental accidents. It appeared to be the least effective derivative tested. All of the *s*-triazines, nevertheless, showed considerable efficacy as algicides. The fact that structural modification affects their activities to a considerable extent suggests that they also should be tested further for use as both general and selective algicides, particularly at low rates of application.

The coefficient of variation found in these experiments ranged from 20 to 25%. In its present form, therefore, the precision of the nutrient-perlite method for algicides is equal to or greater than that of similar methods commonly used for preliminary evaluation of chemicals as herbicides. Both of these types of evaluation can be

criticized from the standpoint of whether results are meaningful with respect to conditions of ultimate use. There is little doubt, however, that preliminary herbicidal evaluation programs in the past have contributed greatly to the development of new and more effective chemicals for the control of weeds. The nutrient-perlite technique might easily satisfy a similar function in the development of algicides, if its use is restricted to the preliminary selection of chemicals which show some potential. Further evaluation, then, would depend on field testing methods or on secondary screening for selectivity and relative potencies by laboratories with more elaborate facilities. Through substitution of pure cultures of algae for the mixed inoculum used in these studies and through maintenance of more precise control over humidity, temperature, and light the nutrient-perlite method might also be adapted to certain secondary phases of evaluation.

SUMMARY

A new method for screening algicidal chemicals, using nutrient-moistened perlite as a substrate and employing greenhouse culture conditions, is described. The method is well adapted for inclusion in a number of existing screening programs. Preliminary evaluation of 14 chemicals has demonstrated considerable algicidal potential for four substituted-urea herbicides and seven *s*-triazine derivatives. All of these compare very favorably in performance with copper sulfate. Dichlone and CIPC were not as effective as the copper sulfate standards.

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Control of Weeds in Late Sown Flax Plots with MCPA and TCA[1]

W. E. Sackston[2]

Introduction

Flax in Uruguay is normally sown in July and August. The common weeds in flax, radish (*Raphanus sativus* L.) and *Rapistrum rugosum* L., in the Cruciferae, and *Ammi majus* L., in the Umbelliferae, are readily controlled by hormone-type weed killers. Experimental plots of flax may be sown from May to September or even later. The weed problem in plots is different from that in farm fields. Plots sown in May or June are usually relatively free of weeds; plots sown in July or later may be heavily infested by various weed species, both broad-leaved and grasses.

The hormone herbicides have made possible the effective control of many dicotyledonous weeds; these are rapidly being replaced in importance by grass weeds. In many flax-growing areas of Canada and the United States, green foxtail (*Setaria viridis* (L.) Beav.) and other annual grasses are extremely troublesome. Dunham (2) reported in 1951 that TCA controlled *S. viridis* in flax in Minnesota. When 2,4–D was added to the TCA, the spray controlled both grasses and broad-leaved weeds. Bakke (1) applied sprays containing TCA and MCPA, singly and in combination, to flax in Iowa. He found that the combined spray controlled grasses and broad-leaved weeds. The success achieved by these investigators led to similar work in 1956–57 in late-sown flax plots at Instituto Fitotecnico, La Estanzuela. This paper reports the results of that work.

Materials and Methods

Tests were made in increase plots of three flax varieties: Pergamino 6098, Pergamino 6808, and Minuano, sown September 18, 1956. The individual plots were 20 meters long by 2 meters wide. The dicotyledonous weeds present included knotweed (*Polygonum aviculare* L.), wild buckwheat (*P. convolvulus* L.), and field bindweed (*Convolvulus arvensis* L.). The main grass weed was crabgrass (*Digitaria sanguinalis* (L.) Scop.). The herbicides used were MCPA, sodium salt of 2-methyl-4-chlorophenoxyacetic acid, 33 per cent acid equivalent (Duperial Agroxone 4[3]), and TCA, sodium salt of trichloroacetic acid, 90 per cent acid equivalent[4]. The MCPA was applied at

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[3]Duperial Agroxone was provided through the courtesy of Ing. Agr. Armando G. Kelly, Industrias Quimicas Uruguayas "Duperial", Montevideo, who also loaned his experimental plot sprayer.

[4]Dupont TCA was provided through the courtesy of Sr. Bruce W. Empson, Dupont Division of Mateo Brunet S. A. C., Montevideo.

the rate of 1.25 pints of Agroxone (3 oz. of acid equivalent) per acre (1.5 liters per hectare), and the TCA at 5.8 lb/A acid equivalent (6.5 pounds of commercial TCA per acre or 7.5 kilograms per hectare). Some plots were treated with both products mixed together, each chemical at the same rate as when it was used alone. The herbicides were applied in water at the rate of 35 gallons per acre (325 liters per hectare) from a Vermorel knapsack sprayer equipped with a boom and four porcelain "Jet" nozzles, Bray 739, spaced 12 inches apart.

All treatments were made on October 24, when the flax plants were 4 to 6 inches tall. The dominant weeds at the time of treatment were knotweed, in the two- to four-leaf stage, seedlings of crabgrass just emerging above the soil, and a few small patches of wild buckwheat. The numbers of weeds in each plot were determined at the start of the experiment by counting all plants in two areas of 0.25 sq. meter, at 5 and 10 meters respectively from the north end of each plot. Twenty-five days after treatment, on November 18, when the flax had just begun to bloom, additional counts were made. All plants in the same two sample areas in each plot were pulled, wrapped in waxed paper, and taken to the laboratory, where they were identified as flax, knotweed, grass, and miscellaneous weeds. Each lot was weighed and counted.

Differences in appearance of the plots were noted at intervals, and photographs were taken. The central three rows of each plot were harvested on January 3, 1957. The total weight of straw and seed was recorded, and after threshing, the yield of clean grain was determined.

The experiment was laid out in randomized blocks with five replicates, and the data were analyzed by analysis of variance. Differences in yield due to varieties were confounded with differences due to replicates.

RESULTS

The day after the chemicals were applied, flax plants in plots treated with MCPA alone or in combination with TCA, appeared slightly wilted, but soon recovered. Five days after treatment, knotweed plants in plots sprayed with the combination of chemicals were starting to shrivel. Twenty-two days after treatment, on November 15, untreated check plots contained heavy infestations of knotweed and light to moderate infestations of grass weeds in patches. Plots treated with TCA contained heavy infestations of knotweed and few grass plants. Plots treated with MCPA contained relatively few knotweed plants, and light to moderate infestations of grass in patches. Plots treated with both chemicals contained very few, small, knotweed plants, many dead seedlings of knotweed, and only traces of grass plants. Wild buckwheat plants were few in most plots, and the leaves appeared scorched in plots treated with the combination of chemicals. A close view of a check plot, showing the spaces between the rows completely filled with weeds, is given in Figure 1A; and a

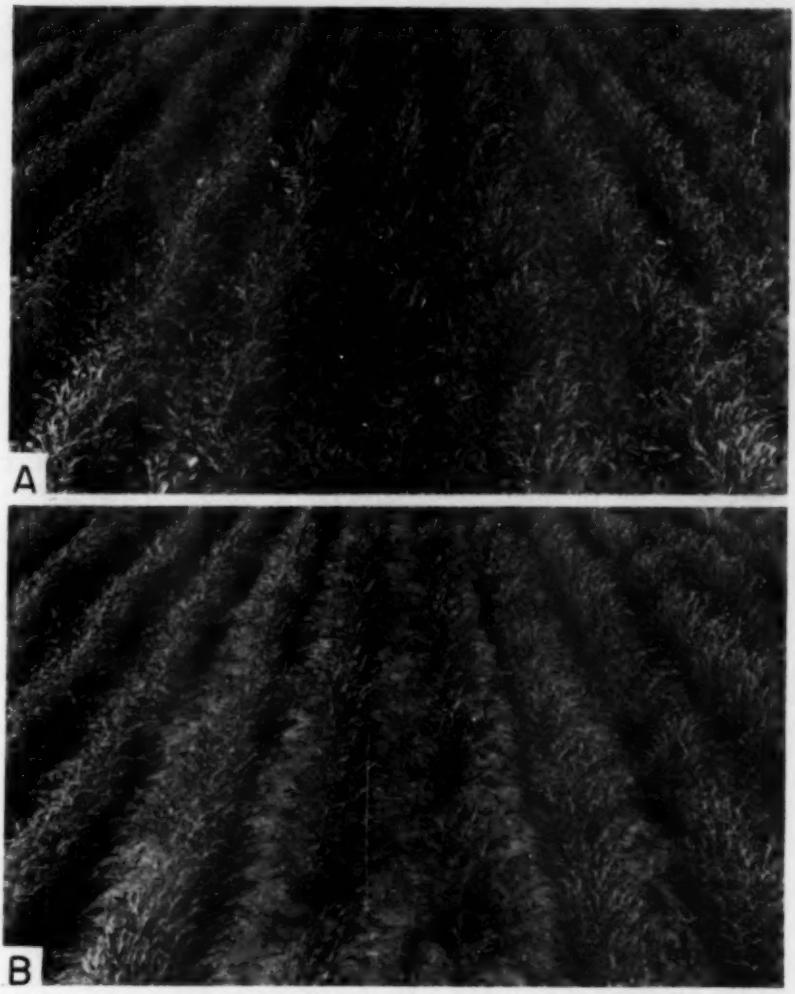

Figure 1. Flax plots photographed November 15. A, untreated check plot showing heavy infestation of weeds; B, plot treated with a combination of MCPA and TCA showing good control of weeds.

close view of a plot treated with both chemicals, showing clean rows and bare soil between the rows, is given in Figure 1B. The photographs were taken November 15.

On November 15 it was observed that flax plants in plots treated with MCPA, alone or with TCA, were slightly shorter than those in the other plots. The first bloom was recorded November 16. On December 1, there was still considerable bloom in all plots treated with MCPA, alone or plus TCA; the other plots were almost finished blooming. On December 19, all plots were maturing well,

but the flax in plots treated with MCPA, alone or with TCA, was slightly less mature than in the other plots. The slight delay in flax development induced by MCPA is characteristic of other hormone herbicides as well.

The numbers of various weeds in each plot determined at the beginning of the experiment, and the numbers found on the same sample areas 25 days later, expressed as percentage survival, are given in Table 1.

Using the term "better" to indicate differences significant at the 5 per cent level, and "very much better" for differences significant at the 1 per cent level, the percentage survival data for knotweed indicate that TCA plus MCPA gives better control than either TCA or MCPA, and is very much better than the untreated check; TCA and MCPA are not significantly different, and both are better than the check.

The percentage survival values for grass weeds show that a lower percentage survived treatment with TCA than with TCA plus MCPA, but the difference was not quite significant. TCA was better than either the check or MCPA. TCA plus MCPA was better than MCPA alone, but was not better than the check.

Counts of the numbers of weeds and the percentage survival after treatment give a fairly good indication of the effects of herbicide treatment, but plant weights, given in Table 1, provide more critical information. Thus, although MCPA treatment reduced knotweed plant population by only 25 per cent from the original count, it reduced plant weight by about 75 per cent below that of the check plots; and although TCA reduced the number of knotweed plants by more than 40 per cent, it reduced plant weight by about 60 per cent. The combination of chemicals reduced knotweed population by 70 per cent, but reduced plant weight by about 92 per cent. The effect on grass weeds was the opposite. Plots treated with MCPA had 120 per cent as many grass plants as before treatment, but the plants weighed about 250 per cent of the check samples; treatment with TCA reduced population by about 75 per cent, but reduced weight by only 55 per cent; and the combination of chemicals reduced grass plant population by over 30 per cent, but weight by only 5 per cent.

The effects of herbicide treatment on the numbers of flax plants in the test area of each plot, and the weight of flax plants per 0.5 square meter, are given in Table 2. The differences in plant numbers and weights of flax samples from plots treated with the respective herbicides were not statistically significant.

The effects of the various treatments on yields of flax seed and straw, calculated as pounds per acre, are also given in Table 2. The effects on yields of grain were highly significant. TCA plus MCPA was not significantly better than MCPA, but was very much better than TCA or the check; MCPA was not quite significantly better than TCA, but was very much better than the check; the difference between TCA and the check was not significant. The effects of the various treatments on yields of straw, although not as great as the effects on grain yield, followed the same trend.

Table 1. Effect of herbicides on survival and weight of weeds in flax plots.

Treatments	Knotweed			Grass			Miscellaneous			Total weeds		
	Initial count[a]	Per cent survival[b]	Weight grams[c]	Initial count	Per cent survival	Weight grams	Initial count	Per cent survival	Weight grams	Initial count	Per cent survival	Weight grams
Check	176	100	204	97	74	18	87	49	50	360	81	272
TCA, 5.8 lb/A acid equiv	136	57	71	98	26	8	69	29	20	304	41	99
MCPA, 3 oz/A acid equiv	101	75	45	60	120	42	70	11	16	231	67	103
TCA + MCPA, 5.8 lb/A + 3 oz/A	133	31	17	141	68	17	50	3	2	324	43	36
LSD 5% level		28	78		55	24		22	30		25	86
1% level		40	110		N.S.	N.S.		31	N.S.		35	121

[a]Initial counts are mean values for 5 replicates, total of 2 counts of 0.25 square meter for each plot.
[b]Per cent survival values are means of 5 replicates, calculated from numbers of plants counted in same sample areas 25 days after treatment.
[c]Fresh weight of surviving plants 25 days after treatment.

Table 2. Effect of herbicides on numbers, weight, and yield of flax plants.

Treatments	Blooming		Harvest	
	Plants per 0.5 sq. meter	Plant weight in grams	Seed yield lbs./A	Straw yield lbs./A
Check	53	95	465	859
TCA, 5.8 lb./A acid equiv.	39	88	512	917
MCPA, 3 oz./A acid equiv.	32	73	567	1044
MCPA + TCA, 5.8 lb./A + 3 oz./A.	59	102	620	1068
LSD. 5% level	N.S.	N.S.	64	141
LSD. 1% level			91	N.S.

DISCUSSION

It was expected that MCPA might give some control of knotweed, and that TCA might control annual grass weeds as it controls green foxtail in North America. Dunham (2) and Bakke (1) reported significant control of broad-leaved weeds by TCA. The effect of TCA on knotweed in Uruguay is therefore not surprising. Bakke found that the combination of TCA and MCPA was less effective against broad-leaved weeds than either chemical alone. The significantly better control of knotweed achieved with a combination of TCA and MCPA than with either chemical alone was unexpected and warrants further, more detailed investigation.

The results presented above indicate that, at least under the conditions of this experiment, grass weeds were not nearly as important as knotweed. However, the grass weeds reacted as they have done in Canada and the United States. Treatment with MCPA, which damaged only the knotweed, gave a marked increase in the number and vigor of grass plants.

The competition of knotweed may account for the fact that the weight of grass weeds was affected less by the respective chemicals than were the number of plants or the percentage survival. Treatments that reduced the vigor of knotweed, although they may have reduced the number of grass plants as well, permitted the survivors to develop more luxuriantly and to attain greater weights than in the presence of vigorous knotweed plants.

The increased yields of flax seed harvested in plots treated with MCPA, alone or in combination with TCA, are of interest because they indicate the financial returns that may be gained by weed control. The increased yields of straw are also of practical importance. In Argentina, and in North America, the straw of oil flax is being utilized on a fairly large scale in the production of cigaret paper and other high quality papers, and it may also be used in other industries.

SUMMARY

TCA and MCPA were applied singly and in combination to late-sown linseed flax plots in Uruguay. TCA gave good control of crabgrass *(Digitaria sanguinalis* (L.) Scop.) and some control of knotweed *(Polygonum aviculare* L.). MCPA gave good control of knotweed. The combination of chemicals gave better control of knotweed than either chemical alone.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the assistance received in the course of this study. Ing. Agr. Gustavo J. Fischer, Subdirector, Instituto Fitotecnico y Semillero Nacional, provided facilities and assigned help as required for field work. Ing. Agr. Olga Campal de Cortabarria permitted the use of her flax increase plots, and arranged harvesting and threshing by her assistants.

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A Study of Factors Which Influence Effectiveness of Amitrol and Dalapon on Common Cattail[1]

F. L. Timmons, L. W. Weldon, and W. O. Lee[2]

Introduction

Cattails *(Typha spp)* are common and troublesome emergent aquatic weeds throughout the United States. They interfere with proper utilization and maintenance of irrigation and drainage canals. They further interfere with flow of water in channels where water velocity is low, and cause deposition of silt. In reservoirs, farm ponds, marshes, and lake margins, cattails waste large quantities of water, crowd out plants which produce food for wildlife and often interfere with fishing, boating, and other uses of these bodies of water.

Expensive mechanical operations such as draglining and chaining in canals and underwater mowing or handcutting in ponds and lakes have often been utilized to remove cattail and provide temporary control. Research (8, 10) has shown that cutting cattail below the waterline twice in one year, first at the early flowering stage and second, 4 to 6 weeks later, usually kills all or most of the cattail. In recent years, repeated spraying with esters of 2,4–dichlorophenoxy acetic acid (2,4–D) at 4 to 6 lb/A in an oil-water emulsion at high volume has provided an effective and practical method of eliminating cattails (6, 8, 9, 12). Still more recently 3–amino–1,2,4–triazole (amitrol) and 2,2–dichloropropionic (dalapon) have proved to be promising herbicides for control of cattails (1, 2, 3, 4, 5, 7).

Methods and Materials

The experiment reported here was conducted in an irrigation drain in northwestern Wyoming to study the influence of different rates, dates, and volumes of spray and of the addition of diesel oil on the effectiveness of amitrol and dalapon in controlling common cattail *(Typha latifolia)*. All treatments were applied in 1956 and were replicated three times on plots 23 feet long and 12 feet wide arranged systematically along the drain ditch. Each plot extended entirely across the ditch. All of the different treatments were included in one experiment but are shown in Tables 1 to 4, grouped according to the four factors that were studied.

Spray applications were made with a constant-pressure knapsack sprayer equipped with a single-nozzle 5-foot spray wand operated by hand to give uniform coverage. Delivery of spray from this nozzle was calibrated, and the spray application was timed on each plot with a stop watch to give the desired volume of spray.

[1]Investigations conducted cooperatively by the U. S. Department of Agriculture, Agricultural Research Service, Crops Research Division, and the Wyoming Agricultural Experiment Station.

[2]Research Agronomists, Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture, Laramie, Wyoming.

In the rate comparison amitrol and dalapon were applied at split-application rates of 5, 10, and 20 pounds of active ingredient per acre at a preheading stage of growth on June 26 and repeated on September 6, 2 weeks before the average first killing frost in fall. This gave total rates from the two applications of 10, 20, and 40 lb/A (Table 1). All split-application rates were applied in 160 gal/A of spray.

Table 1. Effect of rates of amitrol and dalapon on cattail in split applications June 26 and September 6, 1956.

Treatment No.	Chemical	Rate lb/A	Topkill Sept. 5, 1956	Reduction in stand 1957	
				June 28	Aug. 29
			%	%	%
1	Amitrol	5 + 5	12	94	68
2	Amitrol	10 + 10	30	99+	99
3	Amitrol	20 + 20	45	100	100
7	Dalapon	5 + 5	67	80	66
8	Dalapon	10 + 10	96	99	98
9	Dalapon	20 + 20	99+	99+	100

Amitrol and dalapon were compared at 10 lb/A at three different dates: June 26, July 23, and a split application of 5 plus 5 lb/A on June 26 and September 6 (Table 2). The cattail was just beginning to head on June 26, was fully headed with fully developed catkins on July 23, and was approaching dormancy on September 6.

Amitrol and dalapon were also compared at 10 plus 10 lb/A applied June 26 and September 6 in four different volumes of spray: 40, 80, 160, and 320 gallons of water or oil-water emulsion per acre for each application.

The effect of adding 5 gallons of diesel oil plus 0.2 gallon of non-ionic emulsifier per acre to the spray solution was tested on both amitrol and dalapon at the split-application rate of 10 plus 10 lb/A applied June 26 and September 6. This afforded a comparison of both chemicals at one rate and one volume with and without diesel oil and emulsifier (Table 4).

Visual estimates of topkill on September 5, 1956, and of regrowth on June 28 and August 29, 1957, as compared to untreated check plots, were used as measurements of results. The observations made August 29, 1957, are believed to be more reliable than earlier estimates.

RESULTS AND DISCUSSION

The two heavier rates of both chemicals gave complete or nearly complete elimination of cattail (Table 1, Figures 1, 2, upper). The lightest rate of both amitrol and dalapon was considerably less effective than the higher rates and reduced the stand of cattail only about two-thirds. Dalapon applications made June 26 gave much better topkills of cattail in 1956 than did equivalent rates of amitrol on the same date. However, the final plant kill in 1957 was almost identical for both chemicals at all rates.

Single applications of amitrol at 10 lb/A on June 26 and July 23 were much less effective than the split applications of 5 plus 5 lb/A on June 23 and September 6. The June 26 treatment of amitrol gave practically no control and the July 23 treatment gave only 38 percent reduction in stand (Figure 1, lower) as compared with 68 percent by the split application (Table 2). The single application of dalapon on June 26 reduced cattail stand only 28 percent as compared with 70 percent by the single application July 23 and 66 percent by the split application June 26 and September 6. When retreatments of 10 lb/A

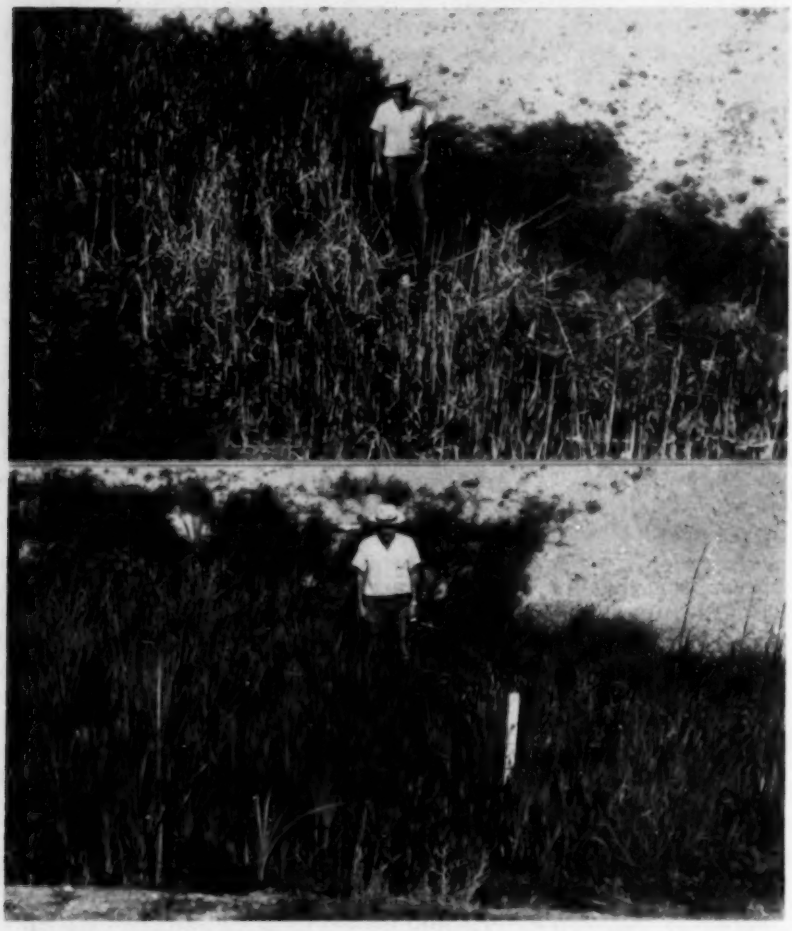

Figure 1. The control of cattail in a drain ditch one year after treatment with amitrol. The upper view shows (left background) an untreated plot and (right foreground) a plot which received two applications of amitrol at 10 lb/A June 26 and Sept. 6. The lower view shows (left) a plot which received 10 lb/A of amitrol at the early heading stage June 23 and (right) a plot which received 10 lb/A of amitrol at the fully headed stage July 23.

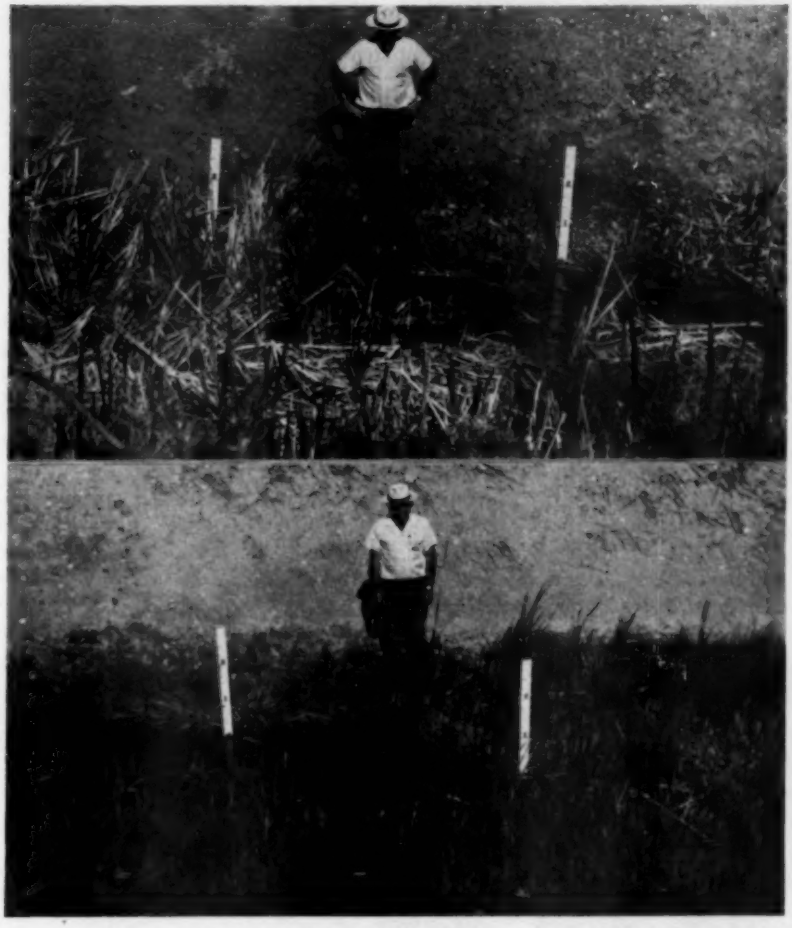

Figure 2. The control of cattail in a drain ditch one year after treatment with dalapon. The upper view shows (left) a plot which received two applications of dalapon at 5 lb/A June 26 and September 6 and (right) a plot which received two applications at 10 lb/A on the same dates. The lower view shows (left) a plot which received two applications of dalapon at 10 lb/A plus diesel oil and emulsifier June 26 and September 6 and (right) a plot which received two applications of dalapon at 10 lb/A without diesel oil and emulsifier on the same dates.

were added September 6 to the 10-pound applications made June 26, both chemicals almost completely eliminated the cattail.

This raises the question as to whether the treatment made June 26 in the split applications actually contributed much to the final kill and whether a single application of 10 lb/A of amitrol or dalapon made September 6 at a mature stage of growth might have been as effective as the split application of 10 pounds June 26 and 10

Table 2. Effect of dates of applying amitrol and dalapon on cattail.

Treatment No.	Chemical	Dates	Rate lb/A	Topkill Sept. 5, 1956	Reduction in stand 1957	
					June 28	Aug. 29
				%	%	%
5	Amitrol	June 26	10	23	6	7
6	Amitrol	July 23	10	18	60	38
1	Amitrol	June 26 and Sept. 6	5 + 5	12	94	68
11	Dalapon	June 26	10	86	63	28
12	Dalapon	July 23	10	85	86	70
7	Dalapon	June 26 and Sept. 6	5 + 5	67	80	66
2	Amitrol	June 26 and Sept. 6	10 + 10	30	99+	99
8	Dalapon	June 26 and Sept. 6	10 + 10	96	99	98

pounds September 6. In earlier work with 2,4–D (6, 9, 11) it was shown that preheading to early heading was the optimum time for the first spray treatment and that a second treatment with 2,4–D in late summer was necessary for effective plant kill. However, both amitrol and dalapon apparently are effective in single applications made at later stages of growth (1, 2, 3, 5). It is possible that one late application of either of these chemicals the first season may be sufficient. However, further experimental work must be done before this conclusion can be drawn.

Volume of spray had no noticeable effect upon the results with amitrol (Table 3) which gave nearly complete elimination of cattail

Table 3. Effect of volume of spray for applying amitrol and dalapon on cattail.[a]

Treatment No.	Chemical	Volume gal/A	Topkill Sept. 5, 1956	Reduction in stand 1957	
				June 28	Aug. 29
			%	%	%
14	Amitrol	40	15	99	98
15	Amitrol	80	48	99+	98
2	Amitrol	160	30	99+	99
16	Amitrol	320	33	100	99
17	Dalapon	40	70	96	89
18	Dalapon	80	68	91	66
8	Dalapon	160	96	99	98
19	Dalapon	320	68	96	74

[a]Rate 10 lb/A applied June 26 and repeated Sept. 6.

in all volumes tested. With dalapon the effect of volume was somewhat inconsistent, 40 and 160 gal/A being the most effective and 80 and 320 gallons the least effective. Some investigators have reported (2, 5) that good results have been obtained from both dalapon and amitrol applied in low volumes of spray by airplane. Additional research is needed to determine the most effective volume for dalapon and the lowest effective volume for amitrol.

The addition of 5 gallons of diesel oil plus emulsifier gave a large and significant increase in the effectiveness of dalapon both in original topkill and in final plant kill (Table 4, Figure 2, lower). The

Table 4. Effect of addition of diesel oil to amitrol and dalapon spray on cattail.[a]

Treatment No.	Chemical treatment	Topkill Sept. 5, 1956	Reduction in stand 1957	
			June 28	Aug. 29
		%	%	%
4	Amitrol with diesel oil	62	99+	99
2	Amitrol without diesel oil	30	99+	99
8	Dalapon with diesel oil	96	99+	98
10	Dalapon without diesel oil	68	90	56

[a]Rate 10 lb/A applied June 23 and repeated Sept. 6.

addition of oil to amitrol greatly increased the topkill in 1956, but the plant kill in 1957 was nearly complete both with and without oil. Probably a lower rate of amitrol would be necessary to test the beneficial effect, if any, of adding diesel oil to the spray solution. With 2,4–D the addition of diesel oil and emulsifier has been found necessary (6, 8, 9, 11) for effectiveness in controlling cattail.

SUMMARY

Early-season applications of amitrol and dalapon were less effective on cattail than late-season applications at a more mature stage of growth. Twenty pounds per acre in split applications was much more effective than 10 lb/A and just as effective as 40 lb/A. Forty gallons per acre was as effective as higher volumes of spray with amitrol, but the relation of volume of spray to effectiveness of dalapon was not clear. The addition of diesel oil and emulsifier greatly increased the effectiveness of dalapon but did not increase the effectiveness of amitrol on cattail.

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The Comparative Toxicities of Four Phenylurea Herbicides in Several Soil Types[1]

T. J. Sheets[2]

The herbicides, 3–(*p*–chlorophenyl)–1,1–dimethylurea (monuron) and 3–(3,4–dichlorophenyl)–1,1–dimethylurea (diuron), have been widely accepted as selective soil applied herbicides; they are now used in a number of crops and under a wide range of soils and climatic conditions. Their extreme residual herbicidal activity contributes to their success as residual pre-emergence herbicides and as semipermanent soil sterilants.

The hazards to cereals seeded in the fall or winter following cotton treated with selective rates of monuron or diuron have been recognized, and studies relating specifically to this injury have been conducted (1, 10). In California severe monuron injury has occurred in young beans and tomatoes which were seeded between 5 and 6 months after application of 0.75 to 1.0 lb/A of monuron as a pre-emergence spray to spinach.

Most investigations of the effect of soil type on the phytotoxicity of the phenylurea herbicides have dealt with monuron, although certain investigators studied both monuron and diuron (6, 9). The objectives of the tests reported here were (a) to investigate the initial and residual toxicity of four phenylurea herbicides in several soil types, (b) to relate initial toxicity to clay content, organic matter content, cation exchange capacity, or pH and (c) to study the variations in rates of inactivation among the four herbicides and several soil types. The results will be evaluated from the standpoint of toxic residues under semiarid and arid conditions.

Review of Literature

Monuron and diuron have received much attention in agronomic research since their introduction as herbicides. Certain fundamental aspects of their phytotoxicity have been investigated also. Because these compounds are active mainly through the soil, much emphasis in research has been placed on soil relationships. This is true particularly in the case of monuron. Ogle and Warren (14) demonstrated that the activity of monuron was greater in mineral soils than in an organic soil when the same amount of chemical was applied. They attributed the shorter residual life of monuron in muck soil to a tremendous capacity for monuron inactivation and decomposition.

Sherburne and Freed (19) reported a high degree of correlation between the amount of monuron adsorbed and the organic matter content of soils. They also reported a significant correlation between adsorption and clay content but no significant correlation between

[1]Cooperative investigations of the Crops Research Division, ARS, USDA and the Calif. Agri. Exp. Sta.

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pH and the amount of monuron adsorbed. They suggested that ample but not excessive moisture would tend to overcome the loss of effectiveness due to adsorption. Day (6), using oats as an indicator crop, studied the initial phytotoxicity of monuron and diuron in 26 California soil types. He expressed his results as "minimum lethal dose" in order to readily compare soil types. He measured a 10-fold difference in the lethal dose of monuron across soils and a 50-fold difference in the lethal dose of diuron across soils. He further indicated, however, that under field conditions the effective dosage would probably not show such wide variations.

Studies in Mississippi (10) have indicated that pre-emergence applications of 1.0 to 1.5 lb/A of monuron or diuron to cotton would not be hazardous to oats the following winter if the soil was thoroughly mixed prior to seeding oats. However, in Arizona a 1.0 lb/A application in July has caused cereal injury in the fall (1). Hollingsworth (10) suggested thorough mixing of the soil following pre-emergence band applications of 2 to 4 lb/A of either herbicide to eliminate injury to oats seeded in the following fall or winter.

From the growth of cover crops on treated field plots and chemical analyses of soil samples therefrom Hill and McGahen (8) and Hill *et al.* (9) concluded that monuron and diuron disappeared from soils at about the same rate and that both compounds were inactivated at rates sufficient to prevent accumulation. Danielson's results showed a rapid inactivation of low rates of monuron in a sandy clay loam soil under field conditions (5). When applications at rates up to 5 lb/A were repeated annually for a total of three applications, accumulation did not occur. This same worker stated that the phytotoxicity of 50 lb/A of monuron disappeared in 2 years when the herbicide was mixed with top 5 inches of soil.

The persistence of 3–phenyl–1,1–dimethylurea (fenuron) in soils was studied at several locations by Sharp *et al.*, and according to these investigators fenuron was inactivated quite rapidly under field conditions (17). Corn and sorghum plants grew normally in soil taken from plots which were treated with 25, 100, and 400 lb/A of fenuron 16 months earlier.

Hill *et al.* (9) concluded that biological decomposition was the main course of detoxification of monuron and diuron, but they recognized that leaching, volatilization, and chemical- and photodecomposition might contribute to loss of toxicity under certain conditions. Other workers have presented data supporting the view of microbial inactivation for diuron, fenuron, and 3–(3,4–dichlorophenyl)–1–methylurea (DMU) as well as for monuron (13, 14, 18).

Several investigators have studied the movement of monuron and diuron in soils, but they have not clearly demonstrated differences in the rates of leaching of these two compounds. Bioassay of soil samples taken from field plots in Mississippi indicated that both monuron and diuron remained within the 0 to 1 inch level of soil after receiving 9 inches of rainfall (10). Loustalot *et al.* (13) reported that monuron did not move beyond the surface inch of soil; however they used low rates of simulated rainfall. Hill *et al.* (9) stated that

some movement downward of monuron occurred when large volumes of water were used; however under field conditions they did not detect monuron or diuron below the 4-inch level and hence concluded that loss by leaching under field conditions was not of great importance. Ogle and Warren (14) demonstrated that some movement downward of monuron occurred in a fine sand and a silt loam, but it was quite resistant to movement in a muck soil. They assumed that monuron was retained in an active form by the soil.

EXPERIMENTAL PROCEDURE

Approximately 120 pounds of each of 17 soils were thoroughly mixed. A sample of each was taken for determination of the various soil properties (Table 1). The soils were screened, and a stock mixture was prepared for monuron, diuron, fenuron, and DMU in each soil. The concentrations were prepared by weighing aliquots of the

Table 1. Methods of determining the soil properties.

Determination	Method	Comments
Mechanical analysis	Hydrometer method (2, 11).	Samples dispersed by shaking 24 hours with sodium hexametaphosphate as a dispersing agent. Three determinations.
Organic matter per cent	Walkley-Black rapid titration method for organic carbon (15).	Duplicate determinations.
Cation exchange capacity	Quick determination of cation exchange capacity (16).	Not recommended for acid soils. Expressed as milli-equivalents per 100 gms of oven dry soil (in Table 2). Duplicate determinations.
pH	Glass electrode, Photo Volt Electronic pH meter (15).	Readings made on soil samples, which were brought to a saturated paste by addition of distilled water. Duplicate determinations.
Moisture equivalent	Standard centrifuge method (2).	Used as a measure of field capacity. Three determinations.

soil-chemical mixture followed by thorough mixing with sufficient untreated soil to bring the total weight of the cultures to 500 grams of oven dry soil. The treated cultures were placed in No. 2 metal cans. All treating was accomplished with air dry soil. The concentrations were: 0.0, 0.17, 0.5, 1.5, 4.5, 13.5, 40.5, and 121.5 ppmw. A randomized split block design was used with three replications. Herbicides were the main plots and soil types the subplots. The experiment was conducted in the greenhouse.

The biological method for determining the initial and residual toxicity of herbicides in soils has been described (4, 12, 18). Immediately following treatment of the soils all cultures were watered to field capacity and 13 Kanota oat seeds were planted per can. The cultures were watered at least daily and often twice daily as required during the time the crops were growing; consequently soil moisture was adequate for the growth of oats during the cropping period. At the end of 30 days after seeding, fresh weights of oat plants above the soil level were recorded. The cultures were allowed to dry for the next 30 days. At the termination of this period all cultures were

pulverized, the plant refuse of the previous harvest returned to the soil, and all cultures watered to field capacity and reseeded to oats. This sequence of testing was continued for a total of seven crops.

In order to make direct comparisons among soil types, chemicals, and croppings, ED_{50} values were determined. The ED_{50} represents the 50 per cent effective dose; i.e., the amount of herbicide in ppmw which reduced growth by 50 per cent. Each ED_{50} was obtained by plotting the fresh weights as per cents of the control against the logarithm to the base 10 of the concentrations (X 10) and constructing a free hand curve to fit the points. The concentrations were multiplied by 10 to avoid use of negative logarithms. The point on the concentration axis which corresponded with the point of intersection of the curve and the 50 per cent yield level was the ED_{50} as a logarithm. The antilogarithm of the 50 per cent point (divided by 10) gave the ED_{50} as the actual concentration of the original treatment.

An analysis of variance was performed on the logarithm values and the LSDs in Table 2 were computed from this analysis. The correlation and regression analyses were performed on the logarithm data also. The computations involving rates of inactivation were performed using the ED_{50} values as actual concentrations of the original treatments.

Comparative leaching studies involving monuron and diuron were conducted using soil columns 2 inches in diameter and 20 inches high. The columns were formed by attaching end to end with water resistant, electrical tape six lidless and bottomless metal cans 2 inches in diameter and 2.875 inches high. An additional can of the same diameter was attached to the top of the column; in this manner sufficient space was available in the column to maintain a water head. Still another can with the bottom attached but punctured (15 holes, each approximately 2 mm square) was attached to the lower end of the column. This can supported the soil column but also allowed drainage. After the columns were filled with soil, they were sub-irrigated to field capacity prior to treatment. The herbicides were applied to the surface as a dry soil-chemical stock mixture. Following treatment the appropriate volume of water was added to the surface as a water head. Twenty four hours after drainage ceased, the columns were sectioned by cutting the tape, the contents of each can dumped into a paper cup, and 10 oat seeds planted to each. Movement of the herbicides was determined by injury and fresh weights of oats 3 weeks after seeding. All treatments were run in duplicate.

RESULTS AND DISCUSSION

Relationships of initial phytotoxicity and soil type. The ED_{50} values for the first cropping are given in Table 2. These are expressed as actual concentrations and as logarithms (to base 10) of the concentration multiplied by 10. The actual concentrations were included for ease of interpretation. The LSDs can be used to compare any two observations as logarithms in the table. Differences between

Table 2. The cation exchange capacity, per cent organic matter, per cent clay, and pH, and the ED_{50} values the first cropping expressed as ppmw and as the logarithm of the ED_{50} (x 10) by soil types.

Soil type	Cation exchange capacity	Per cent organic matter	Per cent clay	pH	ED_{50} values[a]							
					Fenuron		Monuron		Diuron		DMU	
					Act	Log	Act	Log	Act	Log	Act	Log
Egbert series	31.2	6.0	69.5	7.2	1.0	.97	1.0	1.00	4.0	1.60	7.4	1.87
Tulare clay	13.0	2.1	52.7	7.8	.8	.90	.7	.83	1.5	1.17	3.2	1.50
Yolo silty clay	25.7	2.4	45.0	8.0	.4	.63	.6	.77	1.9	1.27	5.4	1.73
Sacramento clay	26.3	1.7	63.6	7.8	.6	.77	.3	.50	.3	.47	.9	.93
Aiken clay loam	8.2	9.8	33.7	5.5	1.6	1.20	1.4	1.13	2.9	1.47	5.1	1.70
Stockton adobe clay	29.6	3.8	50.0	6.1	.9	.93	1.0	.97	2.7	1.43	5.4	1.73
Fresno clay	23.7	3.4	42.5	6.8	.5	.67	.3	.47	.7	.83	2.0	1.30
Madera clay	22.5	3.5	40.5	6.8	.6	.77	.5	.67	.7	.87	1.4	1.10
Merced clay loam	20.4	2.2	34.3	7.4	1.1	1.03	.5	.73	.9	.97	1.7	1.23
Yolo clay loam	20.2	1.9	33.0	7.0	.3	.47	.3	.53	1.4	1.13	3.2	1.50
Panoche clay loam	14.5	.9	32.7	8.2	.3	.43	.2	.23	.3	.47	.8	.90
San Emigdio clay loam	14.2	1.1	27.7	7.8	.2	.30	.1	.10	.2	.37	.7	.87
San Joaquin loam	8.1	2.2	22.0	5.8	.9	.93	.4	.60	.9	.93	1.5	1.17
Yolo sandy clay loam	13.9	1.3	22.5	7.1	.3	.43	.3	.43	.7	.83	1.9	1.27
Hanford loam	8.1	1.6	17.5	6.8	.6	.73	.3	.53	.7	.83	1.5	1.23
Delano sandy loam	6.4	.5	15.6	6.8	.5	.67	.2	.17	.2	.20	.3	.43
Hesperia sandy loam	7.5	.3	15.0	7.5	.2	.20	.1	.10	.1	.10	.2	.33
LSD between soil type means as logarithms within a chemical at the 5% level												.14
LSD between soil type means as logarithms within a chemical at the 1% level												.18
LSD between chemical means as logarithms in the same and in different soil types at the 5% level												.17
LSD between chemical means as logarithms in the same and in different soil types at the 1% level												.24

[a]Act—ED_{50} in ppmw.
Log—Log. of the ED_{50} (x 10).

two values as actual concentrations can be determined by making the same comparison in the logarithm data.

The range in effective concentration, from the soil in which the ED_{50} was lowest to the one in which the ED_{50} was highest, varied among the four herbicides (Table 2). The extreme ED_{50} values for fenuron were 0.2 ppmw in the San Emigdio and Hesperia soils and 1.6 ppmw in Aiken clay loam; for monuron 0.1 ppmw in the San Emigdio and Hesperia soils and 1.4 ppmw in Aiken clay loam; for diuron 0.1 ppmw in Hesperia sandy loam and 4.0 ppmw in the Egbert soil; and for DMU 0.2 ppmw in Hesperia sandy loam and 7.4 ppmw in the Egbert soil. Although the ratio of the largest ED_{50} to the smallest ED_{50} for monuron was greater than that of fenuron, the actual differences between the two extreme ED_{50} values were approximately the same for the two chemicals (Table 3). The ranges

Table 3. Differences between the two extreme ED_{50} values in ppmw by chemicals and the ratios of the largest ED_{50} to the smallest ED_{50} the first cropping. (From Table 2).

Comparison	Chemical			
	Fenuron	Monuron	Diuron	DMU
Actual difference between the extremes	1.4	1.3	3.9	7.2
Ratio $\frac{\text{largest}}{\text{smallest}}$	8	14	40	37

and the ratios of the ED_{50} values were much greater for diuron and DMU. The magnitude of the differences between the extremes are strongly indicative of the tenacity with which these herbicides are adsorbed. The results for monuron and diuron are in agreement with those of Day (6). These observations indicate that, in types of soil treatments in which the herbicides are mixed or become dispersed in the soil, the effective dosage among soils would vary less with monuron than with diuron.

In this experiment a majority of the soils required from two to four times as much diuron as monuron to give equal activity (Table 2). The difference in effectiveness of monuron and diuron may be less or non-existant under field conditions depending on the cultural treatment and climatic factors. If the herbicides are in a thin layer on the soil surface, as for example following a pre-emergence application, the concentration may be sufficiently high to partially or wholly mask the effect of adsorption. Rainfall and cultural practices such as disking, and perhaps photodecomposition also, may accentuate or conversely eliminate the difference in effectiveness of these two herbicides. This effect of adsorption may also be masked when high rates are used, even though movement and dispersal in the soil occur.

Table 4 shows that simple correlations were found between the ED_{50} and cation exchange capacity, per cent organic matter, and per cent clay. Positive correlations indicate that the amount of herbicide required to reduce the fresh weight by 50 per cent increased as the values of the soil properties increased. Although no significant correlation was obtained between the ED_{50} and pH of the soils, the coefficients for all four herbicides were negative. In the interpretation of the simple correlations it must be recognized that soil properties may vary together. Significant correlations were found among per cent organic matter, cation exchange capacity, and per cent clay (Table 5); pH did not show any particular relation with the other three factors. In addition to the inter-relationships, any one of these soil factors may vary concurrently with some unknown or undetermined factor in the soil which could affect results. Varying amounts and types of clay minerals could presumably influence the adsorption of herbicides. Hence, caution must be used in interpreting these data. Contribution of the various factors to toxicity reduction cannot be determined by simple correlations.

Table 4. Simple correlations of the ED_{50} values of the herbicides the first cropping with four soil factors.

Chemical	Cation exchange capacity	Per cent organic matter	Per cent clay	pH
Fenuron	.398′ᵃ	.637**	.522*	−.403′
Monuron	.662**	.810**	.696**	−.261
Diuron	.648**	.807**	.618*	−.256
DMU	.679**	.758**	.635**	−.143

′ Significance at the 10 per cent level.
* Significance at the 5 per cent level.
**Significance at the 1 per cent level.
ᵃr^2 x 100, where r is the correlation coefficient, gives the percentage variation in herbicidal toxicity which can be accounted for by variation in the soil factors. Aiken clay loam was excluded from the analyses.

Table 5. Simple correlations among the soil factors.

Soil factor	Per cent organic matter	Per cent clay	pH
Cation exchange capacity	.777**ᵃ	.846**	.061
Per cent organic matter	—	.762**	−.307
Per cent clay	—	—	.020

**Significance at the 1 per cent level.
ᵃAiken clay loam was excluded from the analyses.

By multiple regression techniques cation exchange capacity, per cent organic matter, per cent clay, and pH can be identified and their individual contribution evaluated. Standard partial regression coefficients suggested that organic matter contributed more to toxicity reduction than either per cent clay, cation exchange capacity, or pH. Again, however, some unknown attribute occurring concurrently with organic matter may have contributed to the relationship.

The results of this test are in general agreement with those of Sherburne and Freed (19) who reported a very high correlation between the amount of monuron adsorbed and organic matter per cent of soils and a significant but much lower correlation between monuron adsorption and clay content. The standard partial regression coefficients also suggested that fenuron might respond differently to the various soil factors than the other three herbicides. This could lend support to the suggestion that fenuron was less highly adsorbed than the other three (18). Certainly the variations in the effective dosage ranges between the four herbicides (Table 3) suggests greatest adsorption of diuron and DMU and least adsorption of fenuron and monuron.

Rates of inactivation. The rates of inactivation of the four herbicides were determined by analysis of ED_{50} values obtained from the fresh weights of seven periodic crops of oats. The method of fitting orthogonal polynomials as given by Goulden (7) was used to determine the relationship of toxicity and time following treatment.

The curves in Figure 1 show that fenuron was inactivated far more rapidly than the other three herbicides; that the inactivation rate of diuron was slowest; and that monuron and DMU inactivation rates were about equal and more rapid than diuron when averaged across all soils. The rates of loss can be determined from the slopes of the curves. The amounts of monuron, diuron, and DMU which disappeared were a linear function of time. The inactivation of fenuron, however, could be fitted to a quadratic equation, and its disappearance appeared to be an exponential function of time.

When the entire test period was considered, fenuron was inactivated most rapidly in all soils except one (Table 6). Monuron was inactivated more rapidly than diuron in a majority of the soils; the rate of detoxification of diuron exceeded that of monuron in only one soil and approximated that of monuron in three others. The disappearance of fenuron appeared to be an exponential function

Table 6. Differences between ED_{50} values of the first and seventh crops.

Soil types	Fenuron[a]	Monuron	Diuron	DMU
Egbert series	7.08	5.22	2.50	13.00
Tulare clay	5.64	2.04	n.s.	3.18
Yolo silty clay	6.36	2.16	3.84	2.46
Sacramento clay	31.00	6.24	4.38	5.34
Aiken clay loam	30.20	6.24	3.24	13.40
Stockton adobe clay	9.66	4.74	4.80	6.66
Fresno clay	73.50	12.40	5.88	5.22
Madera clay	107.00	10.50	4.38	9.30
Merced clay loam	21.20	6.72	5.34	4.86
Yolo clay loam	10.00	1.74	n.s.	3.78
Panoche clay loam	16.60	4.02	1.80	2.34
San Emigdio clay loam	8.16	2.34	1.98	1.92
San Joaquin loam	25.60	4.14	1.44	4.80
Yolo sandy clay loam	13.00	2.40	1.25	3.36
Hanford loam	39.30	5.52	2.28	1.98
Delano sandy loam	53.00	7.80	2.22	4.20
Hesperia sandy loam	19.40	2.70	0.96	2.40

[a]The values were calculated from rate of inactivation equations and are expressed as ppmw of the original treatment. The n.s. notations indicate no significant relationship between toxicity and time at the 5 per cent level of probability.

of time in 7 of the 17 soils. In 2 soils monuron and DMU detoxification showed the same relationship. With diuron this type of function was evident in only one soil. In 2 soils there was no significant relationship between diuron toxicity and time (Table 6), probably because of a very slow rate of degradation. In the remaining soils the amounts of chemicals which disappeared were linear with respect to time.

Microbial degradation has been suggested by several workers as the main course of detoxification of the phenylurea herbicides (9, 13, 14, 18). Although the quadratic relationship of several of the curves may suggest a slow build-up of micro-organisms in certain soils capable of inactivating one or more of the herbicides, limited greenhouse tests designed to show this have so far been negative.

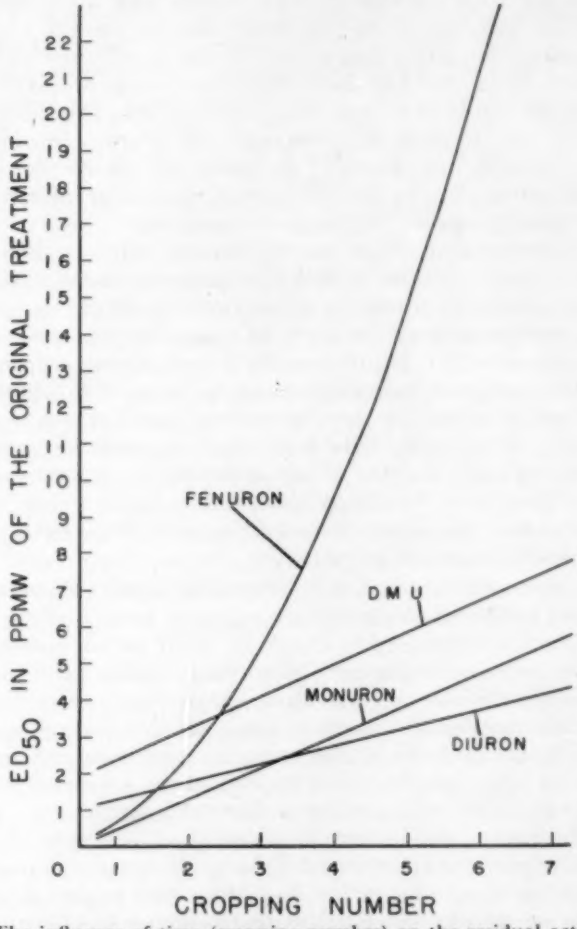

Figure 1. The influence of time (cropping number) on the residual activity of the four herbicides as determined by the growth of oats above the soil level.

Recently it was proposed that the rate of decomposition of herbicides in soils is a function of the original concentration as well as time, moisture, and temperature (3). Graded series of concentrations were employed in the present test, and it is possible that the original concentration influenced the rates of inactivation and hence the shapes of the curves.

Comparative leaching studies of monuron and diuron. In one test the surface of columns of Hesperia sandy loam was treated with sufficient monuron (1.84 lb/A) and diuron (3.42 lb/A) to reduce the growth of oats by 50% throughout the columns. Two surface inches of water failed to move either herbicide from the top section of the columns (see procedure) in sufficient quantities to produce symptoms below. Twenty inches of water caused movement of monuron into the lower four sections of the columns, and no symptoms occurred to oats growing in the top three sections. On the other hand 20 inches of water caused movement of diuron into the second and third section from the top, but severe symptoms occurred to oats growing in the top section also. No symptoms were produced on oats growing in the bottom four sections of diuron columns. The difference between the affinity of monuron and diuron for collodial surfaces as well as their water solubilities appears to influence movement, for greater affinity of diuron is suspected.

When high rates of monuron and diuron were applied to Hesperia sandy loam, movement of both appeared to take place more readily. Symptoms appeared in all sections of the 20 inch columns following treatment with 20 lb/A of monuron and diuron and 5 surface inches of water. Injury was only slight in the bottom section of the diuron columns indicating less movement of this herbicide.

Movement of monuron and diuron downward was much less through columns of Yolo clay loam than through Hesperia sandy loam when the same amount of herbicides (20 lb/A) and water were applied to both soils. That the adsorptive capacity of the soil must greatly influence the downward movement of these herbicides was suggested by Ogle and Warren (14).

Soil residues and accumulation. When the herbicides were applied at low rates in the leaching studies reported here, high volumes of surface water were required in the sandy loam soil to move monuron and diuron measurable distances downward. Sufficient rainfall probably does not normally occur to move either monuron or diuron out of the surface few inches except in sandy soils. Although movement may be slow, particularly in clay and clay loam soils, any movement downward would distribute the herbicides in a greater volume of soil and by dilution decrease the herbicidal activity.

Since the rate of downward movement and the rate of inactivation of monuron are more rapid than with diuron, monuron as a selective herbicide should be less hazardous with respect to herbicide residues in semi-arid and arid climates. Evidence has been presented to indicate that accumulation of these compounds from repeated

low annual applications does not occur (5, 9). These data were obtained in more humid regions of the country where conditions may be favorable for microbial degradation for longer periods than in arid regions. The possibility of accumulation in certain soils from low annual applications cannot yet be ruled out in areas of limited rainfall. The data in Table 6 show that only 0.96 ppmw of diuron was detoxified between the first and seventh crops in Hesperia sandy loam. This represents a period of at least 6 months during which conditions were presumably ideal for microbial activity. Field tests now in progress in the southwestern states should help clarify this problem.

These conclusions are based on greenhouse tests. Factors other than those discussed here may influence inactivation of these compounds. Under field conditions, particularly in drier climates, photodecomposition may be significant (9). Further experimentation is necessary to evaluate the importance of this factor on the decomposition of these and other herbicides.

SUMMARY

The initial and residual toxicities of fenuron, monuron, diuron, and DMU were investigated in 17 soil types under greenhouse conditions. The leaching of monuron and diuron was also studied. The results may be summarized as follows:

The range in effective concentration across soils initially was least for fenuron and monuron. The greatest range occurred with DMU; the diuron range was intermediate.

The 50 per cent effective dose was positively correlated with cation exchange capacity, per cent organic matter, and per cent clay; however these 3 factors were correlated with one another. Organic matter appeared to be contributing more to toxicity reduction than the per cent clay or the cation exchange capacity.

Averages over all soils indicated that fenuron was inactivated most rapidly. The rate of detoxification of diuron was slowest; monuron and DMU were about equal and intermediate between fenuron and diuron in the rate of inactivation. These relationships did not hold in all soils.

At low rates of herbicides, high volumes of surface water were required to move monuron and diuron measurable distances downward through columns of a sandy loam soil. When high rates of herbicides were applied, movement of both appeared to take place more readily. Movement of both herbicides downward was much less through a clay loam than a sandy loam soil. Although movement of both were relatively slow, monuron was moved about twice as fast as diuron in both soils.

It was concluded that monuron as a selective herbicide in semiarid and arid climates should present fewer hazards with respect to herbicide residues in soils than diuron.

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The Effect of Various Factors on the Movement of CIPC in Certain Soils[1, 2]

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Once it has been determined that the primary mode of action of a herbicide is dependent upon entry into the plant through its roots, it becomes important to know what factors will influence its movement in the soil. The findings of Ennis (3, 4) and Baldwin, Freed, and Fang (1) that certain cereals absorb carbamates by means of their roots rather than through their leaves stimulated experiments to study the effects of various soil factors upon the persistence and movement of carbamates in the soil. Blouch and Fults (2) found that the effect of various soil types on the effectiveness of pre-emergence applications of CIPC to several crops was much less than the effect of soil structure and high levels of organic matter. Data presented by Ogle and Warren (9) indicated that organic matter may have considerable effect on inhibiting the movement of CIPC in the soil. They also emphasized that the herbicidal behavior of a chemical in soil cannot be predicted from a study of one soil type, since there appears to be an interaction between soil type and movement of the herbicide. Smith and Ennis (12) reported similar results and also found that oil solutions of CIPC were less mobile than aqueous solutions.

Freed (5) applied 4 pounds of IPC per acre to a Chehalis loam soil which had been treated with various amounts of calcium carbonate and reported that the toxicity of the IPC decreased as the amount of applied lime increased. Logan, Odell and Freed (8) studied the leaching of C^{14} labeled IPC and indicated that there may be a linear relationship between the movement of IPC in a sandy loam soil and the amount of simulated rainfall applied. There was also a suggestion that there may be a relationship between the depth to which the IPC penetrated and the interval of time allowed for leaching.

Linder (7) studied the movement of CIPC in soils as affected by simulated rainfall and various soil types. When 2.5 pounds of CIPC per acre were applied to the surface of a loam soil it was found that practically all of the herbicide was retained in the top 3 mm of soil. In all instances, the CIPC was found deeper in either a sand or sand-loam mixture than it was in a loam soil. This was found to be true regardless of whether or not the simulated rainfall was applied.

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Several experiments have been conducted to determine the distribution of CIPC in soils under actual field conditions. Pray and Witman (10) found that 19 days after application of 7.5 pounds of CIPC per acre approximately 60 percent of the chemical was in the top ½ inch of a sandy loam soil and approximately 30 percent in the second ½ inch layer of soil. On the basis of a field experiment in which 15 pounds of CIPC per acre was applied to a sandy soil, Hollingsworth (6) also reported that the top inch of soil contained the most toxicity.

There has been a high degree of variation in the results of the various experiments carried out to determine the effect of soil factors on the movement of CIPC. Therefore, these experiments were carried out to determine the effect of certain factors on the movement of CIPC in several Maryland soils.

MATERIALS AND METHODS

Six soils were used in these experiments. With the exception of a sandy loam soil, aggregates were used which ranged in size from 1.0 mm to 4.76 mm. Where two pH levels were used, the higher pH level was obtained by adding a calculated amount of calcium oxide to the soil. One month was allowed to elapse before the soil was used, during which time the soil was alternately moistened and allowed to air dry. The pH following this treatment was 7.1. The mechanical analysis, organic matter content and the pH of the soils used are given in Table 1.

Table 1. The mechanical analysis, organic matter, and pH of the soils used in the various experiments.

Soil type	Percent sand	Percent silt	Percent clay	pH	Percent organic matter
Sassafras sandy loam	75.5	10.9	13.6	4.2	0.34
Beltsville loam	41.4	37.0	21.6	6.6	1.04
Beltsville clay loam	27.4	45.4	27.2	6.7	1.61
Beltsville clay loam	23.4	48.8	27.8	6.5	1.78
Beltsville clay loam	21.0	50.0	29.0	5.8	2.54
Tuxedo clay	18.5	18.0	63.5	4.2	0.51

A modified version of the method described by Ogle and Warren (9) was used for tracing the movement of CIPC through the columns of soil. Soil tubes 2.8 inches in diameter and 7 inches long were constructed of paraffin-coated cellophane cheese wrap, and then filled to within an inch of the top with the desired soil.

In some experiments it was desired to saturate the soils with water. This was accomplished by removing the bottom of each tube and fastening a double layer of cheese cloth across it with a rubber band. A metal ring in the bottom of each tube prevented the rubber band from hindering the movement of water in the soil capillaries. One end of the soil column was then placed in 2 inches of water and

soaked for a period ranging from 12 to 24 hours, depending upon the length of time it took the soil to become saturated.

The saturated soil columns were placed on a tension table for 12 to 24 hours at 60 cm of tension. After the interval of 12 or 24 hours had elapsed, the soil columns that were to be treated were sprayed with the appropriate amount of CIPC dissolved in 2 ml of acetone. The herbicide was applied at 4 psi with a DeVilbiss atomizer which was described by Shaw and Swanson (11). The soil tubes which served as checks were sprayed with 2 ml of acetone.

Following the application of the herbicide, 1 inch of glass wool was placed on the surface of the soil and 0.5 or 1.0 inch of water was applied. These rates were chosen as being near normal amounts of rainfall for the time of year CIPC is often applied in Maryland. Depending upon the particular experiment under study, a 2, 5, or 8 day interval was allowed to elapse in order that the effect of time could be evaluated against the depth of penetration of the CIPC. At the conclusion of the given interval, the soil columns were cut into five layers. The location of each layer in reference to the soil surface was as follows: 0 to ½ inch, ½ inch to 1 inch, 1 inch to 2 inches, 2 inches to 3 inches, and 3 inches to 4 inches. The various sections of soil were then placed in petri dishes and 15 cucumber seeds planted. Cucumber seeds were used as it had been determined that they were significantly sensitive to a .05 ppm solution of CIPC in water. A ¼ inch layer of moist quartz sand was placed on the top of each layer of soil prior to placing them in a constant temperature and humidity germinator for 72 hours at 30° C. After the 72 hour interval, the soil slices were removed from the germinator and the growth of the cucumbers was measured.

The design of the experiments described above was a split-plot with 3 or 4 replications. The data were subjected to a split-plot analysis using the treatments as whole-plots and the depths of sampling as the split-plots. Because of the variability in plant growth which is frequently encountered in bio-assay tests of this nature (such as all seeds not germinating) the total length of ten randomly chosen cucumber seedlings out of the original 15 was taken as the value for each split plot.

RESULTS AND DISCUSSION

To determine the effect of the original soil moisture level on the depth of penetration of CIPC in a sandy loam soil and a clay soil, air dry and moist columns of these soils were treated with CIPC and 1 inch of water was applied to the surface. After 8 days, the columns were sectioned and planted with cucumbers.

As may be seen in Table 2, the original soil moisture level affected the depth of penetration of CIPC differently on the two soils. When the air dry sandy loam soil was employed, the CIPC was found to have penetrated to the 1 to 2 inch depth. In contrast, when this

Table 2. The average height of cucumber plants (expressed as % of control) grown on soils of different moisture contents and from various depths in a soil column surface treated with 8 pounds per acre of CIPC and sectioned 8 days later.

Soil type	Original moisture level of soil	Soil depth in inches				
		0–½	½–1	1–2	2–3	3–4
Sandy loam	Air dry	21.1**	29.2**	74.6**	114.5	113.8
Sandy loam	Moist at 60 cm tension	28.8**	80.2	101.9	98.0	91.6
Clay	Air dry	13.9**	20.0**	54.1**	92.1	76.0
Clay	Moist at 60 cm tension	16.9**	17.0**	38.8**	76.4**	75.4**

soil was moist at 60 cm tension, the CIPC was detected significantly only in the top ½ inch layer of soil. The CIPC penetrated to the lowest depth of the soil columns when the chemical was applied to the moist clay soil. However, when the clay soil was air dry the CIPC did not penetrate below the 1 to 2 inch depth. This difference might be due to the fact that in the moist clay there were continuous water columns which would aid in downward diffusion. This would not have been true in the dry clay soil.

The effect of soil type on the movement of CIPC as influenced by applied water and intervals of time was evaluated by applying the CIPC to columns of different soils which were moist at 60 cm tension. The analysis of variance indicated that there was no significant difference between the depths of penetration of the CIPC when the ½ and 1 inch rates of water were compared. It was found (Table 3) that there was a considerable difference between the depths in which the CIPC was detected in a comparison of the sandy loam and clay soils at the conclusion of the 8-day interval. As was found in the previous experiment which employed the use of an 8-day interval, the CIPC moved down to the deepest depth in the clay soil, being found in the 3 to 4 inch depth layer. In the sandy loam soil the CIPC penetrated significantly only to the ½ to 1 inch depth in 8 days. In an experimental situation such as this, the sandy loam would tend to have less continuous water columns than an aggregated clay soil. The depth of penetration in both soil types was equal when the 2-day interval was used, although more CIPC appeared to have moved down in the clay soil. As can be seen in Table 3, in the sandy loam soil the CIPC was found deeper in the

Table 3. The average height of cucumber plants (expressed as % of control) grown on various depth sections in moist soil columns surface treated with 8 pounds per acre of CIPC, as affected by the interval of days between treatment and the planting of cucumbers.

Soil type	Interval of time in days	Soil depth in inches				
		0–½	½–1	1–2	2–3	3–4
Sandy loam	2	14.9**	75.7**	87.1*	80.4**	89.0*
Sandy loam	8	16.6**	78.1**	94.4	96.1	97.5
Clay	2	36.2**	39.2**	36.0**	42.6**	61.0**
Clay	8	21.8**	23.1**	27.6**	65.8**	78.1*

soil after 2 days than after 8 days. The reason for this is unknown. It is suggested that this might be due to the fact that with the 8-day interval bacteria would have had a greater chance to break down the small amount of CIPC that would have leached into the lower layers.

The clay soil at a low and high pH level of 4.2 and 7.1 respectively was used to determine what effect, if any, pH has upon the movement of the CIPC in this particular soil type. The soil, which was at 60 cm tension, was treated with CIPC and leached with either ½ or 1 inch of water. The results of this experiment are given in Table 4.

Table 4. The average height of cucumber plants (expressed as % of control) grown on soils of different pH levels and from various depths in a soil column surface treated with 8 pounds per acre of CIPC.

Soil type	pH	Soil depth in inches				
		0–½	½–1	1–2	2–3	3–4
Clay	4.2	16.2**	18.8**	23.2**	58.0**	74.6**
Clay	7.1	13.8**	13.8**	29.5**	63.0**	99.4

The analysis of variance showed that the effect of applied water was nonsignificant. However, there was a highly significant 3-factor interaction between chemical, pH, and depth. At the low pH the CIPC penetrated to the 3 to 4 inch depth. However, at the high pH level the herbicide was not detected significantly beyond the 2 to 3 inch depth. Possibly the exchange mechanism of the clay soil was altered by the addition of the calcium carbonate, and the CIPC did not move into the 3 to 4 inch depth; or if it did move the small amount may have been rapidly decomposed as bacteria would tend to be more active in a neutral than in an acid soil.

Several Beltsville series soils were used to determine the effect of organic matter on the depth of penetration of CIPC. The moist soil columns were treated with CIPC and leached with ½ inch of water. The organic matter content of these soils ranged from 1.04 percent to 2.54 percent, which would include most normal Maryland agricultural soils.

From the data in Table 5, it can be seen that significant amounts of CIPC were detected in the 0 to 1 inch depth of the soil having

Table 5. The average height of cucumber plants (expressed as % of control) grown on soils of different organic matter levels and from various depths in soil columns surface treated with 8 pounds per acre of CIPC.

Soil type	Level of organic matter-percent	Soil depth in inches				
		0–½	½–1	1–2	2–3	3–4
Loam	1.04	15.7**	59.5*	115.0	94.8	71.6*
Clay loam	1.61	36.6**	100.1	103.8	97.1	94.8
Clay loam	1.78	20.2**	96.1	97.5	104.4	101.8
Clay loam	2.54	17.2**	75.1	90.7	107.1	97.4

the lowest level of organic matter. In the soils having the 3 higher levels of organic matter, the CIPC was retained in the upper ½ inch layer. It is concluded that organic matter had a definite though small effect on the downward movement of CIPC.

SUMMARY

The effect of several factors upon the movement of CIPC in a Tuxedo clay, a Sassafras sandy loam, and a Beltsville series soil was studied. Columns of the soil which were either air dry or at 60 cm tension were sprayed with CIPC at 8 pounds per acre and leached with either ½ or 1 inch of water. Following a 2, 5, or 8-day interval, the soil columns were cut into layers and a cucumber bio-assay was conducted to determine the location of the CIPC. The principal findings are as follows:

1. Moisture level and type of soil had an effect upon movement of CIPC in soil columns. CIPC penetrated to the 1 to 2 inch depth in the dry sandy loam soil, but only to the 0 to ½ inch depth when this soil was moist. In contrast, penetration was to the 1 to 2 inch depth in the dry clay soil and to the 3 to 4 inch depth in the moist clay soil.
2. There was no difference in the depths of penetration of the CIPC when the two moist soils were compared at the conclusion of a 2-day interval. At the end of the 8-day interval it was found that the CIPC moved deeper in the clay soil than it did in the sandy loam soil. When the two soils were dry the depth of penetration was equal.
3. The pH of the soil had an effect on the depths in which the CIPC was detected in the clay soil. The herbicide was found at a deeper depth in the soil at pH 4.2 than it was when the pH was 7.1.
4. Soil organic matter reduced the downward movement of CIPC in a Beltsville series soil.

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Persistence and Penetration of Monuron in Asparagus Soils[1]

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Monuron, 3–(*p*–chlorophenyl)–1,1–dimethylurea, is used extensively for weed control in asparagus. Growers apply approximately 1.5 lb/A of monuron in the spring before harvest begins, and the same amount in late June at the end of the harvest season. Each application usually controls weeds for 6 to 8 weeks. Since this chemical controls weeds for such a long period, growers are concerned as to whether, after continued use on the same soil for a period of years, this material might accumulate in the soil to the point where asparagus is injured, or the soil might be made unfit for crops which might follow asparagus. Therefore, a study was made of the persistence and penetration of monuron in soils of asparagus experiments where this chemical had been applied each year for a number of years.

The persistence and penetration of monuron in soils has been studied elsewhere under varied conditions. When applied to a sandy clay loam soil in Virginia at rates of 1 and 2 lb/A, monuron did not remain in sufficient strength from one season to the next to be toxic to snap bean or sweet corn seedlings, according to Danielson (3). When this herbicide was applied at 1 and 2 lb/A to soils of varying texture, Hill *et al.* (4) found that phytotoxic concentrations disappeared within 4 to 8 months, with negligible amounts penetrating to the 4 to 8 inch layer. When monuron at a 1.6 lb/A rate was applied to a loam soil in Ontario, Canada, Birk (1) found that 31 per cent of this disappeared within 2 weeks after application, after which the rate of disappearance was much less rapid.

Rainfall and irrigation has had little effect on penetration of monuron in most soils (3, 4, 5, 6). However, on a Lakeland sand soil in Florida, Upchurch and Pierce (8) found that simulated rainfall leached this chemical to a depth of 2 feet. Sherburne, *et al.* (7), working in Oregon, found that monuron leaching was proportional to water percolation. They also found leaching to be greater in a sandy soil than in a clay loam and much less when soil moisture was near field capacity prior to application.

Methods and Materials

After several preliminary experiments, it was decided to use bioassays for monuron[3] rather than chemical assays for this study. Four

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crop plants, corn, oats, kidney beans, and cucumbers, were evaluated as possible indicator plants for a bio-assay. Oats was selected because corn and kidney beans were not sufficiently sensitive to monuron while cucumbers were too sensitive. The technique finally adopted consisted of preparing a series of soil-monuron mixtures by mixing air-dry soil with talc containing 10 ppm of monuron. Each mixture, containing the equivalent of 0, 0.2, 0.4, 0.6, 0.8 and 1.0 lb of monuron per acre in the surface 4 inches of soil (i.e., 1,200,000 lb of soil), was potted into five 3-inch pots. Fifteen oat seeds were planted in each of the 5 pots which contained the field soil of unknown monuron level. The pots were placed at random on the greenhouse bench and inserted 3 inches into the bench soil which was kept watered to field capacity. Thus surface watering was only necessary every few days and precluded leaching of monuron. A week after seeding, oat seedlings were thinned to a maximum of 10 plants per pot. Green weight of tops was obtained for each pot 6 weeks after seeding. A growth response curve was then plotted, using these weights. A typical growth response curve is presented in Figure 1. Monuron content of the unknowns was determined by

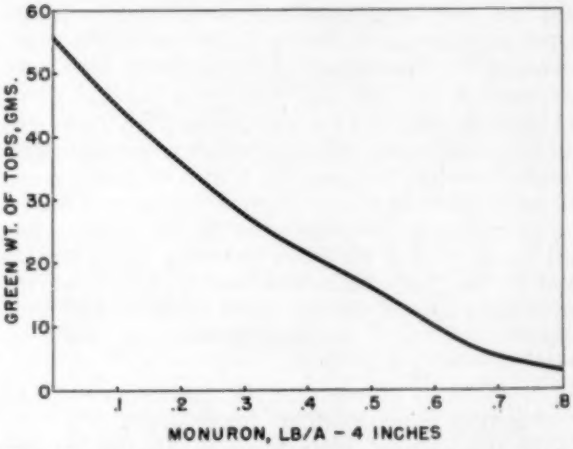

Figure 1. Growth response of oats to varying amounts of monuron in the soil.

relating the green weights to this curve. Since oats rarely grew above the 0.8-lb level, this represented the upper limit for this assay. When monuron levels of the unknowns were higher than this, the unknowns were diluted with the same kind of soil, but which had never received monuron. For example, if the monuron range of the unknowns was 0.8 to 3.0 lb/A, a mixture of one part of unknown soil plus three parts of soil without monuron was satisfactory.

Chemical assays, using the method of Bleidner, *et al.* (2), were found to be very accurate when the monuron content of the soil was determined soon after application to the soil. However, when chemical assays were run 4 or more weeks after the herbicide was

applied to the soil, values much higher than those from bio-assays were obtained. A possible explanation for this is that chemical assays are based on the determination of p-chloroanaline, a part of the monuron molecule that is non-phytotoxic, and which probably is the last part of the monuron molecule to be broken down in the soil by soil microbes.

Three field experiments, which are described below, were used in this study. All treatments were replicated 5 times. Soil samples were taken from the 0 to 4 and 4 to 8 inch layers of soil. Each soil sample was an aggregate of 20 borings which were an inch in diameter. A LaMotte soil sampling tube was used to get these borings.

Effect of application rate and cultivation. Four rates were used: 0.8, 1.6, and 3.2 lb/A applied twice annually (before and after cutting season) and 3.2 lb/A applied once annually (before cutting season). The 3.2 lb rate was applied twice annually for 5 years previous to 1956. The 0.8 and 1.6 lb rates were applied for 4 years previous to 1956. The 3.2 lb rate applied once annually was applied for 2 years previous to 1956. There were two treatments at this latter rate, one where the soil was never disturbed except for the spring discing, and the other which was cultivated three or four times during the season plus the usual discing at the end of the cutting season. This experiment was conducted at Georgetown, Delaware, on Norfolk loamy sand.

Effect of organic matter. This was a long-term asparagus fertilizer experiment from which the following three treatments were selected: (1) Ten tons of poultry manure, (2) 5 tons of poultry manure, and (3) 1600 lb of 5–10–10 fertilizer applied per acre. These treatments were made each year for 10 years prior to this study. The respective soil organic matter levels for plots receiving these treatments were 2.2, 1.8, and 1.3 per cent. Monuron was applied twice annually for 2 years previous to 1956. Two rates were used, 1.2 and 2.4 lb/A. This experiment was conducted at Georgetown, Delaware, on Norfolk loamy sand.

Effect of irrigation. This was an irrigation experiment where three levels of irrigation were used, as follows: (1) No irrigation, (2) medium irrigation, where plots received 2½ inches of irrigation whenever available soil moisture (as measured by a Bouyoucos moisture meter) dropped to 25 per cent at a 2-foot depth, and (3) high irrigation, where plots received 1½ inches of irrigation whenever available soil moisture dropped to 50 per cent at a 2-foot depth. Monuron was applied twice annually for 1 year previous to 1956. Two rates were used, 1.2 and 2.4 lb/A. This experiment was conducted at Newark, Delaware, on Sassafras sandy loam.

RESULTS AND DISCUSSION

Effect of rate of application. No monuron was found in the soil in April of 1955, 1956 and 1957 where rates of 0.8 and 1.6 lb/A were applied twice a year, starting 3 years previous to 1955. These April

samplings were made just prior to the spring application of the herbicide. However, where the chemical was applied at 3.2 lb/A twice a year starting 4 years previous to 1955, some persisted from one year to the next. In 1955 there was 0.4 lb/A in the 0 to 4 inch layer, in 1956 there was 0.3 lb/A, and in 1957 there was 0.3 lb/A. In 1955 there was 0.2 lb/A in the 4 to 8 inch layer, in 1956 there was 0.1 lb/A and in 1957 there was 0.1 lb/A. These bio-assays indicate that there was no "build-up" of monuron from one year to the next at this high application rate of 6.4 lb/A (two 3.2 lb applications) per year.

The persistence and penetration of monuron during a single season 1956, for the three rates mentioned above are presented graphically in Figures 2, 3, and 4. Rainfall during this season was nearly normal (Table 1). The 1.6 lb/A rate is of special interest

Table 1. Monthly rainfall during experimental periods in 1956 at Georgetown and in 1957 at Newark, Delaware.

Month	1956 at Georgetown		1957 at Newark	
	Rainfall inches	Deviation from normal inches	Rainfall inches	Deviation from normal inches
April	2.10	−1.44	3.90	+0.08
May	2.94	−1.06	1.67	−2.14
June	4.76	+1.34	4.27	+0.25
July	5.77	+1.08	1.78	−2.71
August	1.72	−3.93	2.72	−2.56
September	3.91	−0.14	—	—
October	7.40	+4.31	—	—
Total	28.60	+0.16	14.34	−7.08

because this rate is used most extensively by growers. As previously noted, no monuron was present at the start of the season even though this rate had been applied twice a year for the previous 4 years. Following the May 1 application, there was 14 per cent disappearance from the top 8 inches of soil by June 1 (Table 2). By June 22,

Table 2. Percentage disappearance of monuron on four dates from the top 8 inches of soil following three rates of application on May 1 and June 28, 1957.

Monuron applied lb/A	Per cent disappearance following May 1 appl.		Per cent disappearance following June 28 appl.	
	June 1	June 22	July 26	November 1
0.8	20	100	54	100
1.6	14	67	36	100
3.2	25	56	47	92

7½ weeks after application, there was 67 per cent disappearance, indicating an accelerated disappearance after 1 month. Following the June 28 application, there was 36 per cent disappearance by July 26, indicating that the chemical disappeared more rapidly during mid-summer than during the spring. It is interesting to note

that duration of weed control following midsummer applications of this herbicide is usually not as great as following spring applications. Furthermore, at the 1.6 lb/A rate, weeds usually started emerging 6 to 8 weeks after application. This agrees closely with the results presented in Figure 3. By November 1, 1957 all monuron had disappeared.

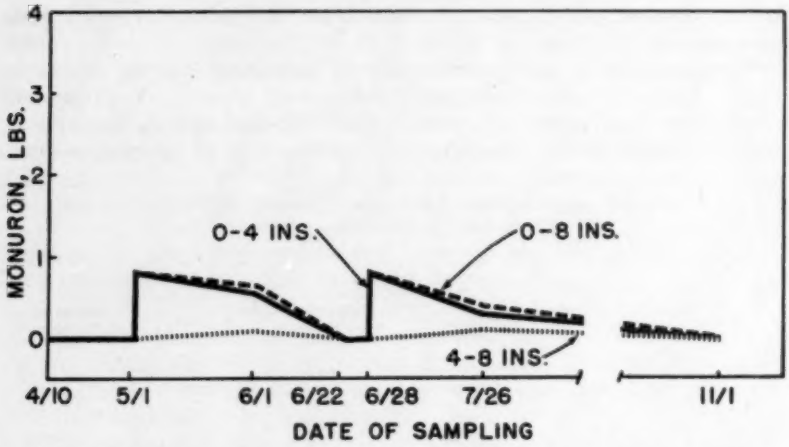

Figure 2. Monuron in 0 to 4 and 4 to 8 inch layers of soil during 1956 where 0.8 lb/A was applied twice annually starting 4 years prior to 1956. Monuron applied on May 1 and June 28, 1956. Monuron level measured by growth of oats.

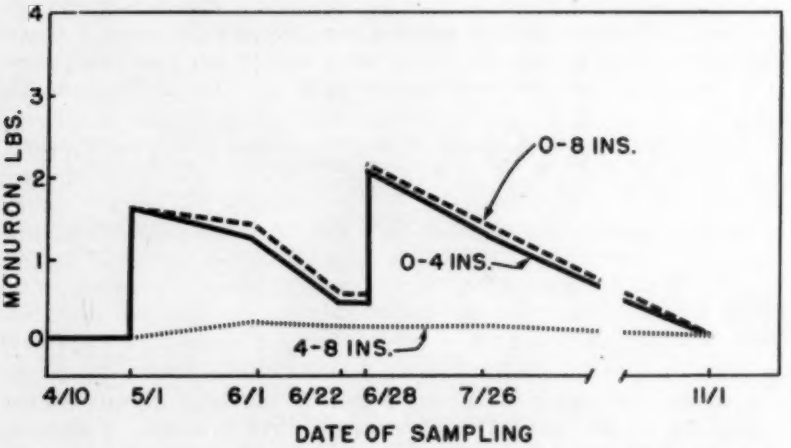

Figure 3. Monuron in 0 to 4 and 4 to 8 inch layers of soil during 1956 where 1.6 lb/A was applied twice annually starting 4 years prior to 1956. Monuron applied on May 1 and June 28, 1956. Monuron level measured by growth of oats.

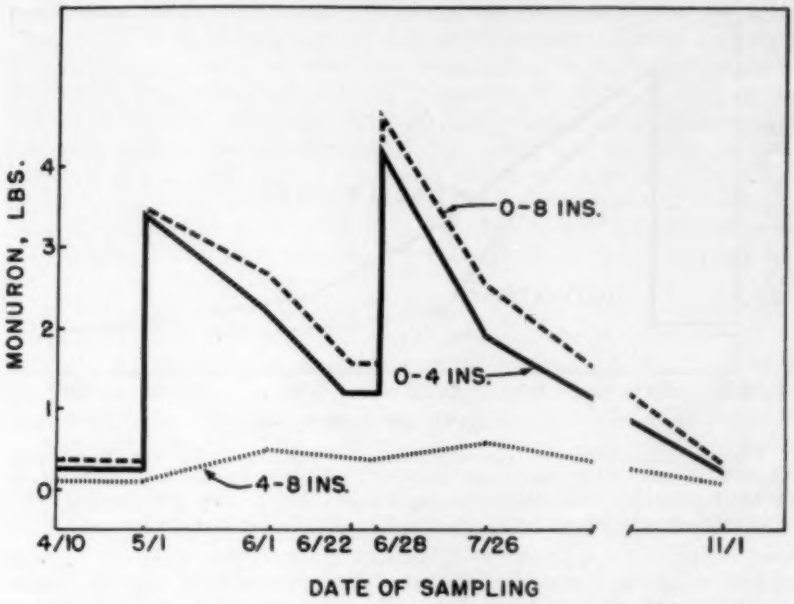

Figure 4. Monuron in 0 to 4 and 4 to 8 inch layers of soil during 1956 where 3.2 lb/A was applied twice annually starting 5 years prior to 1956. Monuron applied on May 1 and June 28, 1956. Monuron level measured by growth of oats.

Some of the herbicide penetrated to the 4 to 8 inch layer at all three rates. Monuron levels in the 4 to 8 inch layer never exceeded 0.1, 0.2, and 0.6 lb/A for the 0.8, 1.6 and 3.2 lb/A rates of application, respectively. This, as stated previously, was in a season of nearly normal rainfall (Table 1). The chemical gradually disappeared from the 4 to 8 inch layer and by November 1 was completely gone except for the plots receiving the 3.2 lb/A rate.

Effect of cultivation. Cultivation accelerated the disappearance of monuron from the soil (Figure 5). At the start of the 1956 season, prior to application, no monuron was present on the cultivated plots but 0.1 lb/A was present on the uncultivated plots in both the 0 to 4 and 4 to 8 inch layers. These treatments were started in 1954 and the herbicide was applied once a year at 3.2 lb/A. On June 22, 7½ weeks after application, 1.4 lb remained in the uncultivated plots at the 0 to 4 inch depth, whereas only 0.4 lb remained in the cultivated plots. Cultivation had no effect on penetration to the 4 to 8 inch layer.

A possible explanation for the more rapid disappearance of the chemical from the cultivated plots is that cultivation speeded up microbial decomposition due to more soil aeration. Hill *et al.* (4) has showed that most of the break-down of monuron in the soil was due to microbial action.

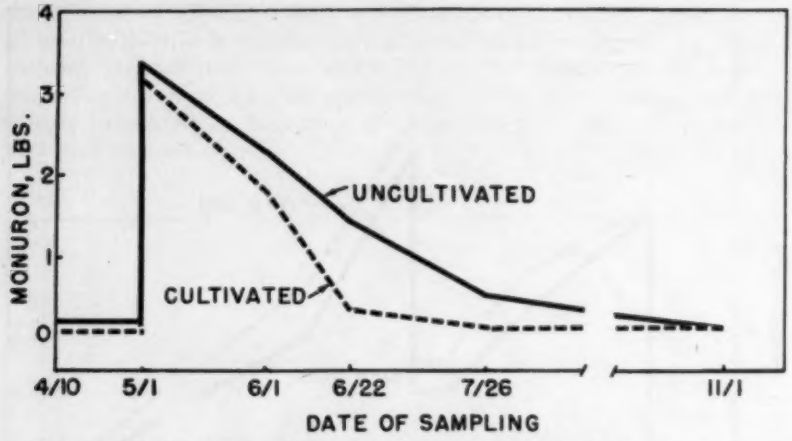

Figure 5. Comparison of cultivated and uncultivated soils for monuron content in 1956 in the 0 to 4 inch layer, where 3.2 lb/A was applied annually starting 2 years prior to 1956. Monuron applied on May 1, 1956. Monuron content measured by growth of oats.

Effect of organic matter. Monuron disappeared at a slightly higher rate from plots having higher soil organic matter content (Figure 6). For example, on July 26, 1956 nearly a month after a 2.4 lb/A application, there were 1.5, 0.9, and 0.8 lb/A in the 0 to 4 inch layer on the low (1.3 per cent), medium (1.8 per cent), and high (2.2 per cent) organic matter level plots respectively. There was no significant difference here between the medium and high organic

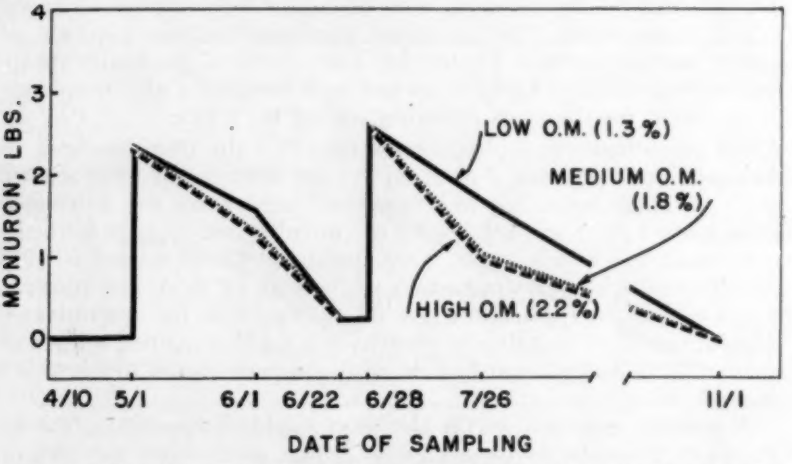

Figure 6. Comparison of soils with varying levels of organic matter for monuron content in 1956 in the 0 to 4 inch layer, where 2.4 lb/A was applied twice annually starting 2 years prior to 1956. Monuron applied on May 1 and June 28, 1956. Monuron content measured by growth of oats.

matter plots. Organic matter levels had no effect on the slight penetration to the 4 to 8 inch layer. A possible explanation for the more rapid disappearance of monuron from plots with higher organic matter is that microbial activity is greater on these plots.

Effect of rainfall and irrigation. In 1956, when rainfall during the growing season was nearly normal, irrigation had no effect on persistence and penetration of monuron which was applied before and after the harvest season at 1.2 and 2.4 lb/A. During the 1956 season, medium irrigation plots were irrigated twice, once in June and once in August. The high irrigation plots were irrigated four times, once in June and three times in August.

In 1957, when rainfall was far below normal (Table 1), particularly following the June 27 application of herbicide, irrigation slightly accelerated the disappearance of monuron from the 0 to 4 inch layer of soil (Table 3). During this season the medium irrigation plots were irrigated twice, once in July and once in August, for a total of 5 inches. The high moisture level plots were irrigated five times, three times in July and twice in August, for a total of 7½ inches. On July 29, a month after herbicide application, plots receiving the 2.4 lb/A rate and no irrigation had 2 lb/A of monuron in the 0 to 4 inch layer (Table 3). Comparable monuron bioassays for the medium and high moisture level plots were 1.3 and 1.4 lb/A, respectively. Irrigation, even at the high rate, had no effect on penetration to the 4 to 8 inch depth.

Table 3. Monuron in soil of plots receiving varying amounts of irrigation during the 1957 season.

Monuron applied lb/A[a]	Soil depth inches	Irrigation level	Monuron in soil on four dates lb/A			
			April 19	May 28	June 27	July 29
1.2	0–4	None	0	0.5	<0.1	0.8
	0–4	Medium	0	0.5	<0.1	0.6
	0–4	High	0	0.3	<0.1	0.7
	4–8	None	0	0.5	0	0.6
	4–8	Medium	0	0.2	<0.1	0.4
	4–8	High	0	0	0	0.5
2.4	0–4	None	0	1.1	0.7	2.0
	0–4	Medium	<0.1	1.3	0.4	1.3
	0–4	High	<0.1	0.9	0.4	1.4
	4–8	None	0	0.5	0	0.6
	4–8	Medium	0	0.3	0.1	0.5
	4–8	High	0	0.3	0	0.4
LSD 5% (Between moisture levels)	0–4	———	N.S.	0.2	0.2	0.4
	4–8	———	N.S.	0.2	N.S.	0.1

[a]Applied April 26 and June 27, 1957.

Again, the more rapid disappearance of the herbicide from the irrigated plots may be explained by greater microbial activity under the more favorable moisture conditions of the irrigated plots.

SUMMARY

1. Bio-assays for monuron were run periodically on soils at 0 to 4 and 4 to 8 inch depths in asparagus experiments where monuron had been continually applied once or twice annually for a period of up to 6 years. Bio-assays were found to be superior to chemical assays for this study because the latter gave values too high when related to plant toxicity.

2. In a 3 year study, monuron did not persist from one year to the next when applied twice annually at 1.6 lb/A, the rate used by most asparagus growers. When twice this rate was used, monuron (0.3 to 0.4 lb/A) persisted from one year to the next but did not accumulate.

3. Monuron disappeared more rapidly following a mid-summer application than following a spring application. Following a mid-summer application, 36 per cent of a 1.6 lb monuron application disappeared during the first month. Following a spring application, 14 per cent of a 1.6 lb monuron application disappeared during the first month. Monuron disappeared from the top 4 inches of soil much more rapidly during the second month than during the first month after application.

4. Some monuron penetrated to the 4 to 8 inch soil depth at all rates used. For the 1.6 lb/A rate of application the maximum level reached was 0.2 lb/A. This disappeared completely by November 1.

5. Cultivation accelerated disappearance of monuron from the soil.

6. Monuron disappeared more rapidly from soils with higher organic matter levels than from soils with lower organic matter content.

7. When rainfall, following monuron application, was far below normal, irrigation slightly accelerated disappearance of monuron from the top 4 inches of soil. Irrigation did not increase penetration to the 4 to 8 inch layer of soil. When rainfall was near normal, irrigation had no effect on persistence and penetration of monuron.

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A Simplified Logarithmic Plot Sprayer[1]

Boysie E. Day[2]

The design and use of a variable-dosage spraying machine for the experimental evaluation of herbicides has been reported by Pfeiffer *et al.* (1). This equipment sprays at constant volume while simultaneously diluting the spray mixture exponentially. The machine is composed of a series arrangement of diluent tank, concentrate tank, pump, and nozzles. The concentrate tank is equipped with a rapid mechanical agitator. The pump propels the spray liquid from the concentrate tank through the nozzles in the conventional manner. The liquid withdrawn from the concentrate tank is replaced by an equal volume of water or other diluent from the diluent tank. Thus the concentration of active ingredient in the spray decreases logarithmically with the volume of spray delivered. Since spray volume is constant with time, by moving the sprayer at constant speed, the rate of application of the active ingredient becomes a logarithmic function of distance along the plot. The machine is mounted on a four-wheel-drive light truck and draws power for the pump and agitator from the power take-off.

The present paper reports the design of a logarithmic sprayer that is simpler, less bulky, and more flexible in use than the original machine described above. The objective was to develop a self-contained machine, compact and light enough to be hand carried, and not dependent for power upon the mounting vehicle.

General Description

The equipment as finally developed is identical in principle with the machine described by Pfeiffer *et al.* (1). The design has been simplified by combining the pump, concentrate vessel, and agitator in one unit. A gasoline-engine-powered centrifugal pump is the major component of the machine. The case of the pump is used as the concentrate chamber. The impeller of the pump serves as the agitator in addition to providing pressure to expel the spray mixture. The intake of the pump is connected, through a check valve, with a diluent tank. The discharge is connected through a quick-opening valve, by individual tubes, to the nozzles. Pressure is controlled by a bypass regulator connected from the discharge to the intake sides of the pump. A separate value is provided for filling the pump. The basic unit, less nozzles, nozzle leads, and diluent tank, is shown in Figure 1. Empty weight of the machine is approximately 35 pounds. Parts for its construction cost approximately $125. It may be mounted on the tool bar of a farm or garden tractor or on a handcart or other suitable vehicle.

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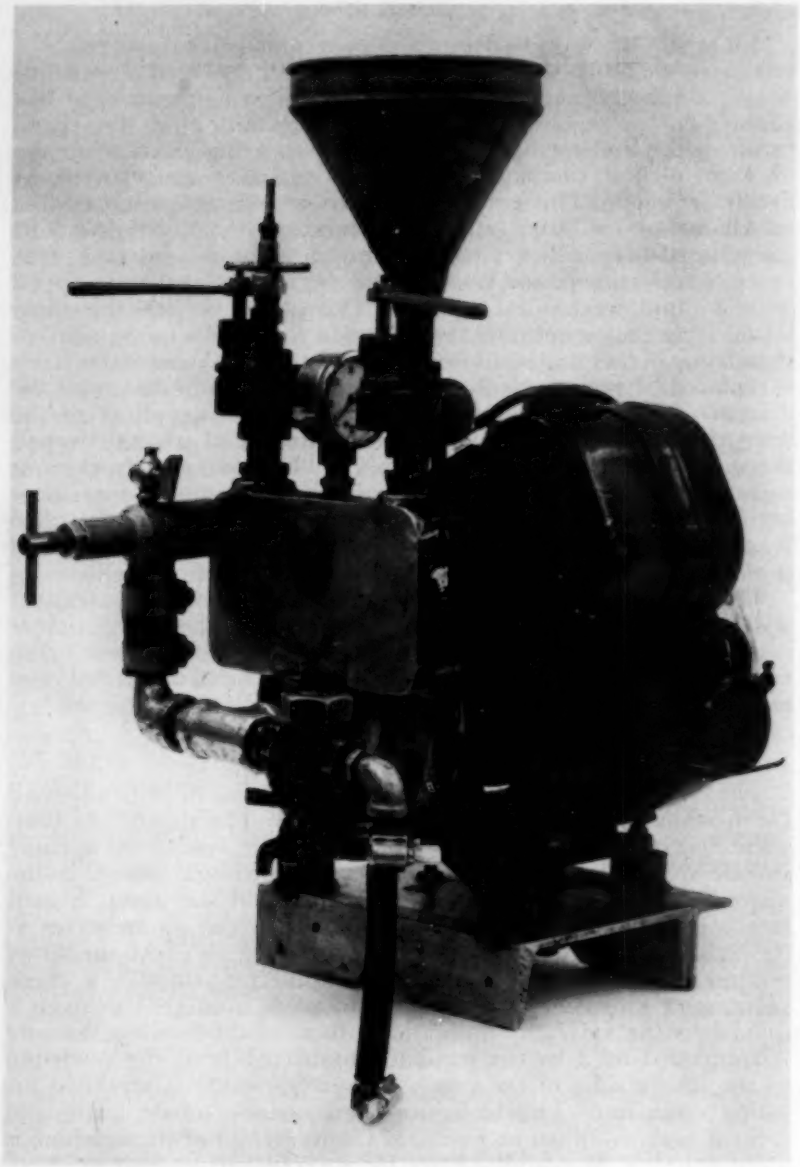

Figure 1. Logarithmic sprayer showing engine, pump, and attached parts. The tank of a knapsack sprayer containing the diluent attaches to the hose in the foreground. Nozzles are fed from separate tubes which connect with the manifold at the left of the funnel. The unit fits inside a rectangular solid 20 x 21 x 12 inches and weighs 35 pounds.

CONSTRUCTION DETAILS

With the exception of the mounting base and the manifold for attachment of the nozzles leads, the machine is assembled entirely of commercially available parts. Figure 2 is a sectional diagram of the sprayer. The lettered references in the following text refer to the components designated by letters in Figure 2.

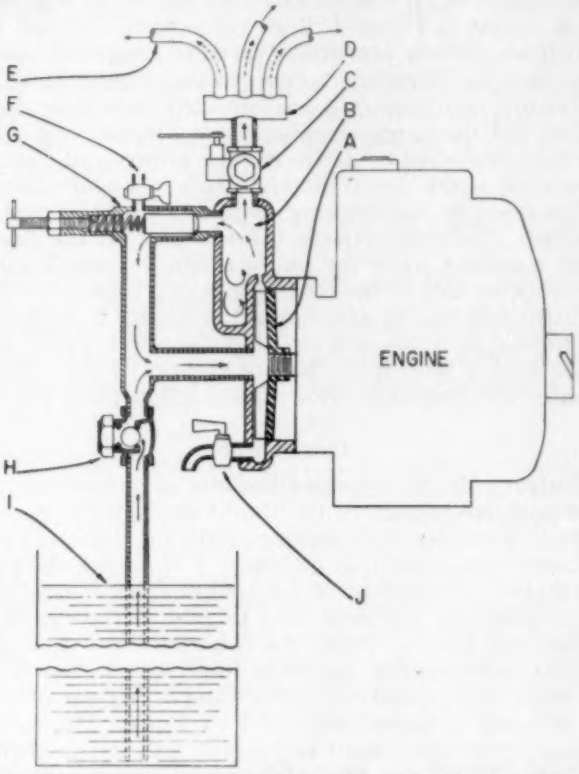

Figure 2. Sectional diagram of logarithmic spraying machine: (A) impeller, (B) discharge chamber, (C) quick-opening valve, (D) manifold, (E) individual nozzle lead, (F) vent cock, (G) bypass pressure regulator, (H) check valve, (I) diluent tank, and (J) drain cock. Arrows show the flow of liquid while spraying is in progress. The filling valve and pressure gauge are not shown. Parts are not shown in their exact spacial relationship to one another.

The pump and engine were purchased as an integral unit.[3] Before modification for its present use the pump was of the "self-priming" type having an intake chamber and a discharge chamber separated by properly ported partitions from the impeller housing. In normal use the function of these chambers is to prevent the pump from fully emptying itself and thus losing prime. In converting the pump

[3] "PUP" pick up pump, Crown Manufacturing Company, Waterloo, Iowa.

for sprayer use, the intake chamber was removed from the pump case by hacksawing, leaving only the impeller housing and discharge chamber (B). With the intake chamber removed the pump case was tapped for connection of the intake pipe at the port already present in the pump case opposite the impeller hub. The discharge chamber was fitted with a quick-opening valve (C) and manifold (D) for connection to individual nozzle leads (E). A valve and funnel for filling the sprayer with concentrate (not shown in Figure 2) were attached as shown in Figure 1. Both valves were installed by means of tapped holes already present. A pressure gauge was mounted in the pump chamber between the two valves (Figure 1). A half-inch bypass pressure regulator (G) was installed in a hole drilled and tapped into the discharge chamber. The low-pressure side of the regulator was connected by means of pipe fittings and a short length of hose to a tee at the pump intake. A hole was drilled and tapped at the high point in the pressure regulator, and the vent cock (F) was installed. The vent relieves the air lock on the low-pressure side of the regulator when the pump is filled. A check valve (H) is fitted to the other side of the tee at the pump intake and connected to the diluent tank (I). As diagrammed in Figure 2, the diluent tank must be located at a lower level than the check valve. It may be placed at a higher level if the ball or clapper of the check valve is spring-loaded to open only on a slight suction from the pump.

OPERATION

Turbulence in the impeller housing and discharge chamber, combined with circulation of the liquid through the pressure-regulating system, provides rapid mixing. With the discharge closed and the regulator adjusted so that no liquid is bypassed, the pump used develops a static pressure of 60 psi (pounds per square inch). The pump characteristics are such that to relieve the pressure to the normal spraying level of 40 psi, the combined flow through the discharge valve and pressure regulator must be 26 gpm (gallons per minute). Depending upon the number and orifice size of the nozzles, the flow of spray is on the order of 1 to 3 gpm. The remainder of the 26 gpm (23–25 gpm) must be relieved and recirculated through the regulator. With this rate of flow the entire contents of the pump-regulator system (790 ml) recirculate through the regulator once each half second. The liquid contained in the regulator and return pipe is replaced every 0.04 seconds. Therefore, as soon as the diluent passes the check valve, it is almost instantaneously swept into the pump and distributed throughout the system.

To place the equipment in operation the pump is primed by filling with water, the engine is started, and the diluent is drawn up to the check valve to eliminate all air in the diluent line. The pressure is adjusted to the desired level with the nozzles spraying, the engine is stopped, and the concentrate chamber is drained by means of the drain cock (J). On the actual equipment the system drains completely back to the check valve although the diagram (Figure 2) is not drawn to show that this can be done. With the drain

cock closed and the vent (F), spraying valve (C), and filling valve open, the pump is filled with a concentrate of the herbicide to be tested. When the vent overflows, the vent cock is closed and filling is continued. When the liquid has filled to the level of the valves, both valves are closed and the engine is started. The sprayer is placed in motion toward the plot area, and as the nozzles pass over a stake placed at the edge of the plot the valve is opened and spraying begins.

CALIBRATION

The instantaneous rate of dilution for equipment of this type is determined by the volume of the concentrate chamber. The concentration after any given volume has been sprayed is governed by the following formula:

$$(1) \quad \log C = \log C_o - \left(\frac{V}{r}\right) \log e$$

C being the concentration of the spray after flow of volume V; C_o, the initial concentration at V = O; r, the volume of the concentrate chamber; and e, the Napierian base. With concentration (C) expressed as percentage of the original (C_o = 100) and volumes expressed in liters (r = 0.79), the formula for the sprayer described becomes

$$(2) \quad \log C = 2 - \left(\frac{V}{0.79}\right) 0.4343$$

or approximately

$$(3) \quad \log C = 2 - 0.55V$$

Calibration tests were made by the colorimetric analysis of a dye solution. Samples were collected by means of a turntable rotating a series of vials beneath a single nozzle connected to the discharge valve. Calibration data confirm that the spray dilution is exponential and that the rate of dilution within limits of experimental error is the same as the theoretical rate. Figure 3 shows calibration data for the machine.

The points on the graph were obtained experimentally. The line was calculated on the basis of equation (3) above for a plot 5 feet wide, sprayed at the rate of 100 gpa (gallons per acre). As the graph shows, the initial concentration is lower than predicted. This is due to dilution of the spray by rinse water remaining in the nozzle leads from the previous run.

The spray mixture becomes diluted to 50 per cent of the original concentration upon discharge of 547 ml (0.693 r). Tenfold dilution is reached at 1820 ml (2.30 r). When spraying 100 gpa the dosage is halved upon coverage of 63 square feet and reduced to one-tenth upon spraying 209 square feet. Thus at 100 gpa the dosage varies tenfold along a test plot 5 feet wide and 42 feet long and sixteenfold along a 50-foot plot. Plot areas for a given range of dilution vary inversely with the spray volume applied per unit area.

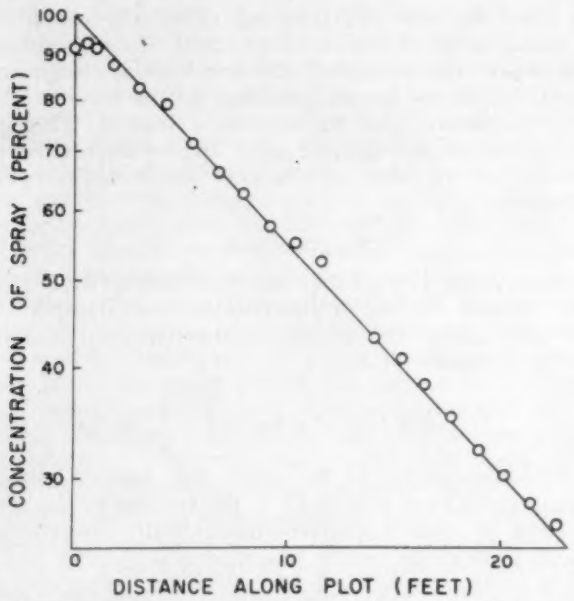

Figure 3. Calibration data for logarithmic sprayer. The line was calculated from the theoretical formula for a plot 5 feet wide, sprayed at the rate of 100 gpa (gallons per acre). The points were obtained experimentally by analysis of samples of spray. The departure from the calculated values at the beginning is due to dilution by rinse water remaining in the nozzle leads from the previous run.

SUMMARY

Design details for a compact, portable logarithmic plot sprayer are given. This equipment sprays at constant volume while diluting the active ingredient in the spray mixture exponentially. A centrifugal pump mounted directly on the shaft of a gasoline engine serves as a power unit to propel the spray, and as a mixing vessel for adding diluent to a concentrate of the test material. The pump discharges the spray mixture through a system of nozzles while simultaneously diluting it with liquid drawn from a separate tank. Thus the concentration of the spray mixture decreases as an exponential function of the volume of spray delivered.

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A Technique for Studying the Relationship of Herbicide Spray Characteristics to Phytotoxicity[1]

W. L. Anliker and M. J. Morgan[2]

The low-volume technique of spray application, which has gained such wide acceptance since the development of the phenoxy-type herbicides, has created problems which did not exist with the high-volume spraying techniques used with contact-type materials. Frequently, when spray applications of systemic herbicides are made, there is only a very narrow margin between the amount of chemical required to kill the weeds and the amount which injures the crop plants. There is evidence that the physical characteristics of both the spray and the plant surface influence some of the responses of plants to herbicides (1, 4, 6, 7). Smith (9) has shown that a surprisingly small percentage of the spray discharged from a nozzle is intercepted by plant surfaces and that the size of the spray particles affects total amount of material retained by the plant. Droplet size is also important since susceptible plants are often injured by small quantities of herbicide which can drift for miles. Moreover, there is evidence that certain plants respond differently to various sizes of spray droplets (3, 5).

Differences in the amount of spray deposited on a plant may contribute largely to the apparent differential response to droplet size. The impact force of the droplets may also contribute. This study was made to investigate some of the physical aspects of herbicide spray applications. The volume of spray liquid intercepted by the plants and not the quantity of spray which was discharged from the nozzles was studied. This approach dealt with the effect of nozzle size and pressure. These are factors which affect characteristics of the spray such as size and velocity, and thus affect the response of the plant to an herbicide. A technique was developed for depositing equal quantities of spray with different sizes of nozzles at various pressures to determine the herbicidal efficacy of sprays of various droplet sizes, as modified by the orifice size and operating pressure.

Materials and Methods

The spraying equipment (Figure 1) was a modification of the machine used by Shanks and Patterson (8). This consisted of a moving platform that passed beneath a stationary nozzle mounted on a boom. The machine consisted of an angle-iron structure which supported a horizontal wood frame. A platform of plywood was mounted on small rollers which allowed it to move the length of the frame on the two angle-iron rails. An endless roller chain extended the length of the wood frame. The chain was driven from sprockets

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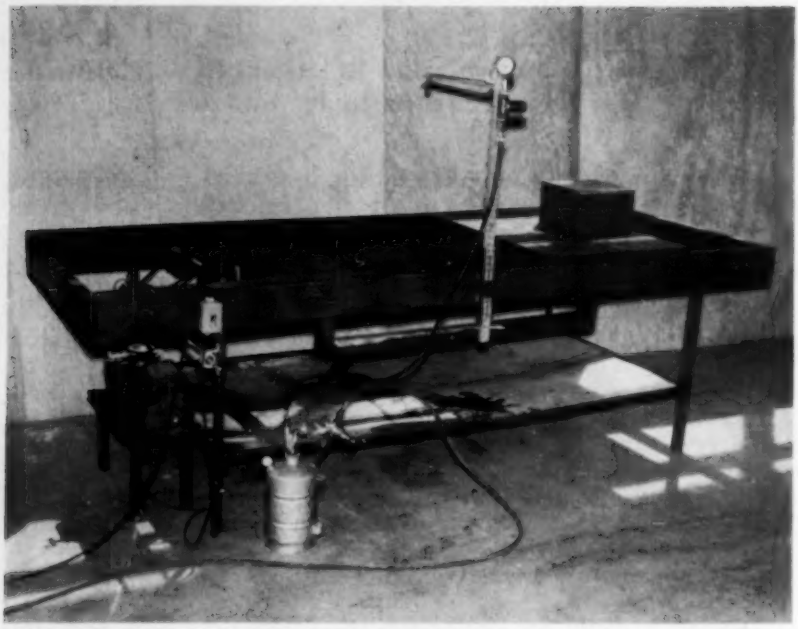

Figure 1. General view of the spraying apparatus, moveable spray platform in place.

mounted on shafts near the end of the frame. A small metal plate was attached to one of the links of the chain. This plate projected out far enough to come in contact with the edge of the movable platform.

A stationary nozzle was mounted above the center of the spray machine so that the spray fan of the nozzle was at right angles to the direction of the movement of the spray platform. It was possible to control the amount of spray applied to the platform surface by regulating the speed of the driving sprocket of the chain. A 1 horsepower (hp) electric motor drove the platform. The speed of the platform was varied from 0 to 5 miles per hour (mph) by means of a variable speed unit in the drive. The platform on which the plants to be sprayed were placed could thus be moved under the nozzle at varying speeds.

The spray nozzle was operated by a hydro-pneumatic system. The operating pressure was precisely controlled with a diaphragm-type air regulator. The steel frame on which the nozzle was mounted was adjusted so that the height of the nozzle above the spray platform could be regulated to correct for variations in the spray angle of the nozzle.

The nozzles used in this study were selected on the basis of uniformity of the spray distribution. Irregularities in the spray patterns of the various nozzles were measured with a corrugated tray similar to the one used by Barger, *et al.* (2). On the basis of this test, three

sizes of flat fan nozzles were selected for use in this study. The three nozzles selected delivered 0.15, 0.067 and 0.033 gallons per minute (gpm) at 30 pounds per square inch (psi).

The application of a uniform quantity of spray liquid to the test surfaces using various nozzle sizes and pressures was accomplished by varying the speed at which the spray platform was moved under the nozzle. The nozzles selected were calibrated by determining the volume of spray liquid discharged per unit of time. A dye solution was used to determine the quantity of spray solution that was deposited on a test surface. An 0.8 per cent solution of pontamine blue, a water soluble dye, was sprayed on the test surface, washed off with distilled water and made up to a standard volume. The color densities of these solutions were determined with an Evelyn photoelectric colorimeter. With this colorimeter, readings were converted to optical density values by substracting the logarithm of each reading from 2.

Bean plants, *Phaseolus vulgaris L.*, were used to determine the effect of propyleneglycol butylether ester of 2,4–D (2,4–dichlorophenoxyacetic acid) sprays, modified by nozzle size and pressure, on plants. The variety Red Mexican was used since it produced large unifoliate leaves at an early stage of development. The plants were grown in individual 3-inch pots. A 0.785 square inch area of a primary leaf on each test plant was exposed to the spray. This procedure eliminated the problem of variations in surface areas among plants.

The apparatus for shielding the rest of the test plant from the spray is shown in Figure 2. This device consisted of an open-top box made of plywood, mounted in the center of the spray platform. One end of the box was removable for ease of placement of the plants in the test stand.

The top of the box was made of 16-gauge galvanized sheet metal with the edges bent down to keep any of the spray from contacting the remainder of the plant. A hole of 1⅛-inch diameter was drilled in the center of the metal top. A small square of brass shim stock was soldered over this hole. A hole 1 inch in diameter was then drilled through the shim stock in the center of the 1⅛-inch hole.

The thin edge of the shim stock offered very little surface for the adherence of spray liquids between consecutive treatments. An adjustable holder was used to position the potted plants so that one of the leaves would be exposed to spray through the 1 inch diameter hole. Previous to treatment the leaf of the test plant was secured to the underside of the opening with a strip of cellophane tape which was easily removed after treatment. The same portion of the leaf surface of each plant was exposed to the spray.

Determination of the physical properties of sprays on herbicidal action required that the volume of spray applied to unit surface area be held constant. This was accomplished by use of the formula:

$$V = \frac{R}{Q \times W}$$

Figure 2. Apparatus for exposing only a portion of one primary plant leaf to the herbicide spray, cover over plant removed.

where V is the speed at which the plant surface is moved through the spray (feet per minute);

R is the quantity of the spray delivered by the nozzles in unit time (gallons per minute);

Q is the quantity of spray applied per unit area (gallons per square foot), and

W is the width of the spray fan at the elevation of contact with the plant surface (feet).

Since the normal spray pattern did not have uniform density, the formula was modified to apply only to the section of the spray fan which intercepted the plant surface. The appropriate R value was obtained for the width of the fan used (W) by a calibration run. The dye solution was sprayed on the 1 inch diameter leaf surface of the test plant, and the technique described above was used in determining the amount of spray applied. An inverse relationship existed between the application speeds and the density of the dye solution. Therefore it was possible to determine the application speeds necessary to cause the actual spray application to approach the desired coverage.

This procedure was followed for the three test nozzles at the pressures of 20, 30, 40, 60 and 80 psi, except for the largest nozzle, 65015. The pressures of 60 and 80 psi were omitted for this nozzle since the application speeds necessary at these pressures were in

excess of the limits of the machine. When the spray applications of dye solution were the same in all treatments, the assumption was made that equal quantities of 2,4–D spray would be applied with each nozzle at each operation pressure.

The level of threshold toxicity for 2,4–D was determined for the test plants by treating them with equal quantities of 2,4–D acid formulations of different concentrations. Concentrations of 800, 1200, 1700 and 2000 parts per million (ppm) were applied to the 0.785 square inch area of the test plants. The concentration of 2000 ppm appeared to be the most appropriate since it definitely deformed the plants and inhibited growth but was not toxic enough to kill the test plants or cause contact burning of the leaf tissue.

The bean plants were treated at the unifoliate stage when the first trifoliate leaves were beginning to open. This was approximately 20 days after planting. The indices of growth response used in this study were the dry weights of the new growth above the primary leaves. The terminal growth of the treated plants was harvested 14 days after treatment and dried. Five individual plants were treated with each combination of nozzle size and pressure and the experiment was replicated five times.

RESULTS

Not all of the bean plants which were treated with equal volumes of 2,4–D spray applied with different combinations of nozzle size and pressure responded in the same way. The growth responses of the test plants to equal volumes of 2,4–D spray applied to one primary leaf of each plant are represented by Figure 3. The dry weights of the terminal growth of the plants were plotted against pressures ranging from 20 to 80 psi to compare the three nozzles used. Highly significant differences existed among some of the 13 spray treatments.

The sprays applied with nozzle 650033 at 20, 30 and 40 psi and nozzle 650067[3] at 20 psi inhibited growth significantly less than did the sprays applied with nozzle 650033 at 60 and 80 psi, nozzle 650067 at 60 and 80 psi and nozzle 65015 at 30 and 40 psi (Table 1). Applications made with nozzle 650033 at 20 psi had significantly less inhibitory effect than the applications made with nozzle 650033 at 60 and 80 psi; nozzle 650067 at 30, 40, 60 and 80 psi; and nozzle 65015 at 20, 30 and 40 psi.

Plant responses to equal quantities of 2,4–D applied with different nozzles and at various pressures were found to differ significantly. A statistically significant value ($P<0.01$) for the linear response to pressure for nozzle 650033 and for nozzle 650067 was obtained from the analysis of variance. For nozzle 65015 there was no significant linear response. This was probably due to the fact that this nozzle was tested at only three pressures. These effects are demonstrated both in Figure 3 and Table 1. The coefficient of variation for the whole experiment was 17%.

The technique developed for applying equal quantities of spray liquid to test plants is of potential value in the screening of potential

[3]Nozzles obtained from Spraying Systems, Bellwood, Illinois.

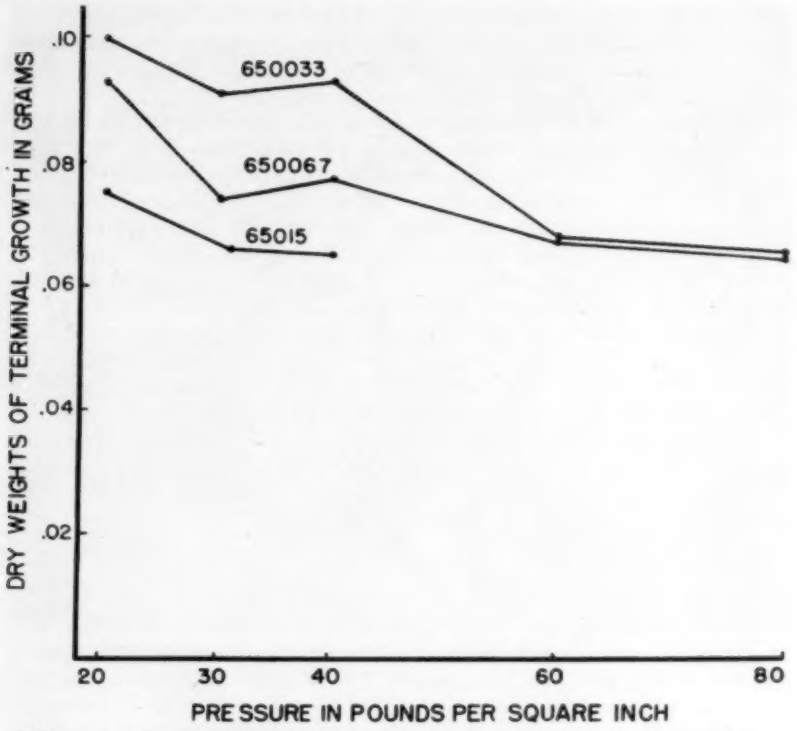

Figure 3. Growth responses of bean plants to constant amounts of 2,4–D as influenced by nozzle size and pressure.

herbicidal formulations. With this method one can accurately compare the responses of plants to chemicals applied in spray form. This technique takes into account the physical as well as the chemical

Table 1. The growth response of bean plants, *Phasaeolus vulgaris L.*, to equal volumes of 2,4–D solution applied with different combinations of nozzle size and pressure.

Nozzle number	Pressure (psi)	Average dry weight of terminal growth in grams[a]
650033	20	0.100 a
650033	30	0.091 ab
650033	40	0.092 ab
650033	60	0.068 c
650033	80	0.066 c
650067	20	0.093 ab
650067	30	0.074 bc
650067	40	0.077 bc
650067	60	0.068 c
650067	80	0.065 c
65015	20	0.075 bc
65015	30	0.066 c
65015	40	0.065 c

[a]If two treatments have a letter in common they are not significantly different. If two treatments do not have a letter in common they are significantly different.

properties of the spray. It is generally accepted that the effectiveness of some formulations is influenced by the nature of certain types of leaf surfaces. A method of applying known quantities of herbicide to plants in spray form could be a helpful tool for studying the compatibility of spray formulations with certain types of leaf surfaces.

Plant epidermal structures such as leaf hairs and wax formations may be of major importance in the varietal response to herbicidal sprays. Wax structures are known to vary among species and among plants of different ages within the same species. Differences in the physical properties of sprays owing to changes in nozzle size and pressure may result in some droplets coming in closer contact with the plant surfaces, thus causing more plant response.

SUMMARY

In order to study the responses of plants to sprays administered with different nozzles and pressures, it was necessary that the same amount of herbicide be applied to each test plant. Quantities of spray applied with three sizes of nozzles at pressures of 20, 30, 40, 60 and 80 psi were equalized by adjusting the speed at which the test plants moved under the nozzle. The average volume of spray applied in all treatments was 2.21 milliliters per square foot, which was equal to 25.4 gallons per acre. A uniform volume of spray liquid was applied to each of the test plants. Young bean plants were sprayed with equal quantities of 2,4–D using three sizes of nozzles with pressures of 20, 30, 40, 60 and 80 psi. An increase in the operating pressure was found to cause a decrease in the terminal growth of the plants.

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Variability in Susceptibility to Injury by DNBP

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Successful use of selective herbicides is dependent upon differences in susceptibility between the crop and the weeds. Often the cause and magnitude of these differences is not completely known. Intelligent use of a chemical requires some knowledge of the margin of safety between the weed and the crop. Beneficial modifications of existing chemicals or methods of application could be most efficiently accomplished if the cause of the differences in susceptibility to the chemical were known. The alkanolamine salts of 4,6–dinitro *o* secondary butylphenol (hereinafter referred to as DNBP) have shown variability in their toxicity to various plant species. This investigation is concerned with the degree and possible causes of this variability.

Materials and Methods

Eight crop plants that varied in many aspects were selected to determine their relative susceptibilities to injury from DNBP and to determine whether such differences were correlated with any known morphological or physiological differences between the crops. The crops were cotton, corn, snap beans, soybeans, peanuts, oats, grain sorghum, and English peas. This group included three plants with linear and five with broad leaves. In four species the hypocotyl elongates and the cotyledons are pulled out of the ground, while in the other four species the cotyledons remain in the ground. In the grass species the stem is enclosed in the coleoptile while emerging and in the leaf sheaths for several days after emerging. The stem or hypocotyl is exposed directly to the chemical in the other species. The seeds varied tremendously in size and in nature of covering. Some of the crops had wax deposits on the cuticle and others had none.

In the first phase of the investigation, the plants were grown in flats in the greenhouse. This phase consisted of three experiments that compared the susceptibility of the eight crops to a pre-emergence application of DNBP. In the second phase, the plants were grown in plastic bags. This phase consisted of six experiments that compared the susceptibility of the crops to the vapor of DNBP with their susceptibility to both vapor and direct contact as in a pre-emergence type of application. The third phase was conducted in a growth chamber and consisted of two experiments designed to determine whether resistant crops secreted some material that inactivated DNBP.

All experiments of the first phase of this investigation were conducted in galvanized metal flats in the greenhouse. The flats were 20 x 14 x 4 inches with perforated corrugated bottoms, and they were placed in larger pans 4 inches deep with drain holes. This

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arrangement made subirrigation possible. There were 10 large pans and each of these held eight flats. Each experiment utilized a single homogeneous lot of pre-mixed Hartselle sandy-loam soil. A single crop was planted in two rows 6 inches apart in each flat. All crops were planted at the rate of 76 seeds per flat except grain sorghum and oats, which had 152 seeds per flat.

The DNBP was applied at five different rates: 0, 3, 6, 12, and 24 pounds per acre (broadcast basis). The rates are expressed on an active ingredient basis and all rates were replicated twice. All crops receiving a given rate of chemical were placed in a single pan. The 10 pans were placed in two rows, and the five rates were randomized within these rows except for the 24-pound rate. This treatment was placed at the end and 4 feet from the nearest pan to avoid the possibility of vapor damage to crops in any other pan.

Soil temperatures were recorded three or four times each day for one flat in each pan. Daily counts were made of the number of seedlings that had emerged, the number living, and the number dead. The experiments were terminated when the chemical had produced its maximum kill. This required from 10 to 18 days, depending on the temperature. The soil temperatures were 90° F or above several times during each experiment with the air temperature ranging approximately 8° higher.

In the second phase of the investigation, the crops were grown in clear plastic bags that were loosely fastened at the top and stretched around 10 x 8 x 20-inch wire frames. The crops were grown in 4-inch clay pots with four pots of each crop placed in each bag. The soil used and the planting procedures were the same as in the first phase of the investigation. Nine seeds were planted in each pot; in the case of grain sorghum and oats, however, 18 seeds were planted per pot. The per acre rates of chemical were: 0, 3, 6, 12, 24, and 48 pounds with the exception of the first two experiments, which did not include the 48-pound rate. Two pots in each bag received the designated chemical rate as a pre-emergence application. The seedlings in the other two pots were subjected only to the vapor from the treated ones. All crops receiving a given chemical rate were randomized within one large pan. The position of the rates was also randomized. There was one bag with four pots for each crop and each chemical rate. The pots were watered by filling the plastic bags until the water rose 2 inches on the pots. The water drained through a tiny hole in the bottom of the bag. Drainage required an average of 2 to 3 hours, which was sufficient time for the soil to wet to the surface by capillarity. Stand counts and temperature records were kept as in the first phase of the investigation. The soil temperatures were 100° F or above several times during each experiment with the air temperature ranging approximately 8° higher.

The third phase of the experiment was conducted at 28° C in a temperature-control growth chamber. In this phase an attempt was made to determine whether plants which are resistant to DNBP secrete a substance which inactivates the chemical. Cotton, because of its high susceptibility to DNBP, was used to determine whether

the chemical was inactivated. Surface sterilized seeds from each of the eight crops were pre-germinated for 2 days in rolls of paper toweling (rag-dolls). Comparable germinating seeds were then transferred aseptically to Petri dishes which contained two sheets of filter paper moistened with 5 ml of distilled water. Six seeds of each crop were placed in each dish except for oats and grain sorghum in which case 12 were used. The seedlings of the eight crops were allowed to grow for 3 days on filter paper in order to allow the hypothesized antagonistic materials to accumulate. The preconditioning crops were then discarded and six pre-germinated cotton seed were placed in each dish. Six additional Petri dishes that had no preconditioning crop were similarly handled. Duplicate treatments of 3 ml of 50 ppm DNBP, 3 ml of 100 ppm DNBP and 3 ml of distilled water were applied to the Petri dishes in each group of six having the same preconditioning treatment. After 3 days the root length was determined for each cotton plant in each dish as a measure of the degree of inhibition of DNBP. This same experiment was repeated.

The percentages of emergent seedlings killed in the first two phases of the investigation were analyzed statistically. Before analysis the values for percentages were transformed to angles (arcsin $\sqrt{\text{percentage}}$) as proposed by Snedecor (3). An analysis of variance was also made on the root length.

RESULTS AND DISCUSSION

Large differences were observed among the crops both in their susceptibility and in the manner of killing by a pre-emergence application of DNBP. Average percentages of crops killed at different chemical rates are given in Table 1. Statistical analysis showed

Table 1. Average percentages of seedlings killed by pre-emergence applications of 0, 3, 6, 12, and 24 pounds per acre of DNBP.

Crop	Av. per cent kill by the various per acre rates of DNBP[a]					Grand av.[b]
	0	3 lb	6 lb	12 lb	24 lb	
Cotton	6.7	7.3	26.9	76.1	100.0	43.4 a
Oats	0.5	15.0	31.7	70.2	85.2	40.5 a
Soybeans	20.0	9.6	22.9	31.0	90.4	34.8 a
Gr. sorghum	8.8	4.5	5.0	32.4	82.3	26.6 b
Eng. peas	1.0	0.3	3.9	8.8	50.7	12.9 c
Snap beans	3.9	4.0	9.2	4.4	24.9	9.3 c
Corn	0.9	1.0	2.3	9.9	30.0	8.8 c
Peanuts	0.8	1.4	0.0	0.0	0.7	0.6 d

[a]The averages are from the six replications in three different experiments.
[b]Values not adjacent to the same letter are significantly different at the 5% level.

that these crops differed significantly (at the 5 per cent level) in their susceptibility to NDBP as follows: cotton = oats = soybeans > grain sorghum > English peas = corn = snap beans > peanuts. Very little correlation could be found between these differences in susceptibility and known differences in morphology. Plants having elongation of the hypocotyl included both the most susceptible crop,

cotton, and the least susceptible crop, peanuts. Crops in which the cotyledons remain in the soil include the very susceptible oats and the rather resistant corn. Both broad-leaved and linear-leaved crops included some very susceptible and some rather resistant species. Corn, soybeans, and English peas are reported by Schieferstein and Loomis (2) to have wax deposits on the cuticle, but they differ widely in their susceptibility. Cotton does not have wax deposits and is very susceptible. The presence or absence of a coleoptile and enclosing leaf sheaths did not seem to affect the susceptibility. The seed size was roughly correlated with susceptibility (Table 2). The larger-seeded species were, in general, more resistant; only grain sorghum varied in this relationship. The relation holds well within the broad-leaved species. Grain sorghum and oats are reversed in the grasses, but their weights may not be significantly different.

Table 2. Average seed weight and variety of each crop plant used.

Crop	Variety	Av. wt. in grams
Grain sorghum	Early Hegari	0.024
Oats	Victorgrain	0.030
Cotton	Coker 100 wilt	0.099
Soybeans	Jackson	0.119
English peas	Thomas Laxton	0.241
Corn	Dixie 18	0.266
Snap beans	McCaslin	0.372
Peanuts	Dixie Runner	0.392

The types of injury induced by DNBP varied with the plant. Cotton, soybeans, snap beans, and peanuts all showed a similar response, but at different chemical rates. In each case, when a lethal rate was achieved, the stem (hypocotyl) was killed near the soil surface and often with the maximum area of injury on the side of the stem closest to the chemically treated surface. The girdled plants fell over, and the tops died apparently because of the disrupted vascular system. The tops often remained green for 2 or 3 days after a section of the stem was dead at the soil surface. At sublethal chemical rates, the outer leaves of corn, oats, and grain sorghum were killed, but the inner leaves and stem survived to continue growth. At the higher rates all of the above-ground parts were killed soon after emergence. At lower rates English peas were killed above-ground, but survived because of continued growth from below ground portions. At the higher rates, the complete plant was apparently killed almost as soon as any portion reached the surface.

Since pre-emergence applications resulted in girdling of some plants near the soil surface, these plants were exposed to DNBP vapor to determine whether this was a place of high susceptibility. It also seemed desirable to determine whether plants that were highly susceptible to a pre-emergence application were equally susceptible to DNBP vapor. These comparisons were made in the second phase of the investigation. The results are givin in Tables 3 and 4. Comparison of percentages killed at a given rate in Tables 1 and 3 shows that the plants were much more susceptible when grown in

bags than when grown in flats. This increased susceptibility may have been due to the combined effects of the vapor and contact action in the bag in contrast to primarily contact action in the flats. However, it may have been a result of altered plant characteristics when grown in the bag. Comparison of Tables 3 and 4 reveals that

Table 3. Average percentages of seedlings killed by pre-emergence applications of 0, 3, 6, 12, 24, and 48 pounds per acre of DNBP.

Crop	Av. per cent kill by the various per acre rates of DNBP[a]						Grand av.[b]
	0	3 lb	6 lb	12 lb	24 lb	48 lb	
Cotton	0.0	40.9	87.4	97.6	84.7	100.0	68.4 a
Oats	4.2	56.7	69.3	91.0	96.8	100.0	69.7 a
Soybeans	1.7	1.2	74.2	96.5	96.0	100.0	61.6 ab
Gr. sorghum	0.0	17.4	36.7	88.4	88.8	100.0	55.2 bc
Eng. peas	0.0	9.6	40.7	66.0	70.4	97.5	47.4 c
Snap beans	0.9	1.9	3.7	22.6	44.8	89.3	27.2 d
Corn	0.0	2.3	8.6	34.0	70.2	100.0	35.8 d
Peanuts	0.0	0.0	3.1	2.2	4.9	2.1	2.1 e

[a]Seedlings were grown in pots placed in plastic bags and the averages are from six replications in six different experiments.
[b]Values not adjacent to the same letter are significantly different at the 5% level.

Table 4. Average percentages of seedlings killed by the vapor from pre-emergence applications of 0, 3, 6, 12, 24, and 48 pounds per acre of DNBP.

Crop	Av. of per cent kill by the various per acre rates of DNBP[a]						Grand av.[b]
	0	3 lb	6 lb	12 lb	24 lb	48 lb	
Cotton	1.2	1.0	38.8	80.1	83.3	100.0	50.7 a
Oats	3.2	25.8	25.8	68.9	73.0	89.6	47.7 a
Soybeans	2.0	2.1	12.0	42.2	71.1	100.0	38.2 b
Gr. sorghum	0.0	0.5	13.8	46.1	70.2	94.6	37.5 b
Eng. peas	2.1	1.9	0.9	4.2	1.6	6.9	2.9 c
Snap beans	0.0	0.0	1.0	0.0	7.3	12.7	3.5 c
Corn	0.0	0.0	0.0	0.9	28.8	62.4	15.2 c
Peanuts	4.2	1.2	1.2	0.0	1.4	0.0	1.3 c

[a]Seedlings were grown in untreated soil in pots placed in the same plastic bag with the chemically treated ones. The averages are from six replications in six different experiments.
[b]Values not adjacent to the same letter are significantly different at the 5% level.

higher percentages of plants were killed when subjected to both the contact and vapor action of the chemical than when exposed to the vapor alone. Nevertheless, the relative susceptibility of one crop as compared with another was not changed significantly whether it was exposed to vapor only, contact only, or to the combination. Any plant that was significantly more resistant than another plant in one treatment remained that way, or it was impossible to demonstrate significant differences between them.

The type of injury induced by vapor was often quite different from that produced by a pre-emergence treatment of the chemical. In all crops, injury symptoms and death occurred later in those exposed to vapor only than in the other plants in the same bag. DNBP vapor killed the leaves of cotton, soybeans, and snap beans first with the stems dying later. The reverse was true with the contact type injury from a pre-emergence application. Since the relative

degree of susceptibility or resistance was essentially the same regardless of whether induced by contact or vapor, it appears that the mechanism influencing the degree of susceptibility must be present in both the leaves and stem.

The third phase of the investigation was based on the hypothesis that resistance to DNBP might be attributable to secretion by the resistant plant of some substance or substances that somehow depressed the activity of the herbicide. Ries (1) has established that the mechanism of species resistance to CIPC is of this nature. This does not appear to be the case with DNBP (Table 5). Since it is

Table 5. The average length in mm of 5-day-old cotton roots as influenced by the growth of a previous crop in the same container and the interaction of this preconditioning with two levels of DNBP[a].

Previous crop	DNBP—ppm		
	0	50	100
None	56.2	——	——
Cotton	58.0	26.2	13.5
Oats	52.5	23.1	8.3
Soybeans	47.7	10.2	6.3
Grain sorghum	56.1	22.8	13.5
English peas	45.7	25.2	9.8
Corn	47.4	26.7	10.3
Snap beans	64.0	27.8	14.5
Peanuts	56.3	15.1	8.3

[a]The averages were obtained from measurements of 24 individuals in two tests each of which had two replications. Probability values: Previous crop >0.10; rates <0.005; rates x previous crop >0.30. LSD among the checks was 8.6 mm (5% level).

possible that the antagonistic substance may remain entirely within the plant, preliminary studies were made to check this theory. Water extracts of seed and of seedlings of resistant species likewise did not furnish any measurable protection to cotton from injury by DNBP.

Thus, it appears that the resistance to injury by DNBP involves a mechanism not fully understood. The resistance is correlated with seed size and thus also with seedling size (Table 2). The larger the diameter of the seedling the greater is the ratio of internal tissues to exposed surface. It appears that one hypothesis of resistance might be based simply on the number of layers of external cells that could be injured without causing death to the plant. It seems probable that the thickness of the cuticle may also be involved. The authors have observed that shade-grown plants appear more susceptible. This might have been correlated with poor cuticle development.

SUMMARY

The variability in susceptibility to killing by DNBP was investigated in cotton, oats, soybeans, grain sorghum, English peas, corn, snap beans, and peanuts. An attempt was made to determine the morphological or physiological basis for this variability. The chemical was used both as a pre-emergence application and as a vapor. The crops had elongating and non-elongating hypocotyls, broad and linear leaves, coleoptiles and no coleoptiles, waxy and non-waxy

leaves, and various seed and seedling sizes. Crops differed significantly in susceptibility to a pre-emergence application of DNBP as follows: cotton = oats = soybeans > grain sorghum > English peas = corn = snap beans > peanuts. The relative susceptibility of one crop as compared with another was essentially the same whether the crop was exposed to vapor only or to contact in a pre-emergence application. However, the effects on the above-ground parts were quite different. Differences in susceptibility were not correlated apparently with any factor except seed size. In general, the larger-seeded species were most resistant. This relationship held most accurately when the comparisons were restricted to the broad-leaved crops.

Cotton was grown in Petri dishes preconditioned by the growth of the other crops in the same containers. Preconditioning by growth of a resistant crop did not protect the cotton from injury by DNBP. Water extracts from resistant seeds and seedlings likewise did not reduce the effect of DNBP.

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The Combined Effect of an Herbicide and Disease on the Emergence of Peanut Seedlings[1]

LYTTON W. BOYLE, ELLIS W. HAUSER, and JACK T. THOMPSON[2]

IN extensive experimental studies with peanuts in Georgia, satisfactory results have been obtained with the pre-emergence herbicide, sodium 2,4–dichlorophenoxyethyl sulfate (sesone) (3, 4). During the past 3 years, the use of sesone for weed control in peanuts has been generally satisfactory and its use as a general farm practice in Georgia has greatly increased. When emergence was poor and the sesone was being used for the first time, some growers were very ready to place the entire blame for poor stands on the herbicide, without considering that poor emergence could, as in the past, result from a variety of other causes.

In view of the tolerance of peanuts to sesone, which had been observed both in experimental and farm plantings, such poor emergence should be considered as either an unrelated, purely coincidental phenomenon, or the result of some correlative factor that had reduced the usual tolerance of the plant. Where poor emergence was obtained after the use of sesone, there was usually some circumstantial evidence that one or more deleterious factors, other than the sesone itself, were contributing to the result. Among the several suspected correlative factors was the prevalence and severity of disease.

The purpose of this paper is to present data from greenhouse studies with peanuts to show the result of the combined action of different dosages of the herbicide and different levels of disease on the emergence of peanuts.

MATERIALS AND METHODS

Where the combined action of sesone and disease had been suspected under field conditions, no specific disease or organism was indicated. Therefore, disease is here understood as the result of a complex of bacteria and fungi that may commonly occur in peanut fields of the area. In this complex, special reference is given to the soil rot fungus (*Rhizoctonia solani* Kunn) and the southern blight fungus (*Sclerotium rolfsii* Sacc.).

The scope and primary intent of this study was to determine the effect of different dosages of sesone when combined with different levels of vitality or emergence due to disease. Different levels of disease or emergence were obtained, as previously reported, by variation in the amount of nutrient available to the microflora in the

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soil at the time of planting (1). This technique is based on the principle that the parasitic fungi mentioned above are necrotrophic (dead-food) in nature and get the energy they require to establish a parasitic relation to the plant, only from dead organic matter. In summary, the more nutrient available to these fungi in the soil, the more active they become, and the more frequent and severe the disease as measured by the percentage of seed planted.

The soil used in these tests was taken from a sandy bottom filled with a heavy cover of grass and some weeds. This soil was tossed through a ¼ inch mesh, without special effort to work it through the screen. In this way, all except traces of organic matter, such as a few short segments of fine roots, were removed. This soil was naturally infested with bacteria as well as the soil rot fungus *(R. solani)*.

The natural inoculum in such soil was supplemented by an artificial inoculum of the southern blight fungus *(S. rolfsii)*. In some cases, the inoculum included the medium of steamed oats on which it had grown. In other cases, where no organic medium was desired in the soil, the sclerotia were separated from such cultures, dried, and cleaned in an air blast, before being used as inoculum.

Different levels of disease or emergence were obtained by placing a supplemental necrotrophic medium of dry soybean leaves and stems with the artificial inoculum in the upper 2 inches of soil for various intervals up to 8 weeks before planting. After preparing the soil in this way, it was kept moist to allow more or less of the nutrients in the medium to be consumed by natural biological processes before planting the peanut seed. Under favorable conditions of temperature and moisture, the frequency and severity of attack by these necrotrophic fungi has been correlated with the amount of nutrient available to them in the soil (1).

The effect of the sesone was compared between three rates of application, 0, 3, and 6 lb. active ingredient per broadcast acre. The 3-lb. rate is the one generally recommended in farm practice with peanuts. The applications of sesone were made with automatically controlled equipment. The plantings were made in 12 inch greenhouse pots and these were placed on a belt which passed at constant speed under a calibrated spray nozzle such as used on field equipment.

In operation of the tests, the eighteen 12-inch pots which were prepared at one time with the artificial inoculum and media were considered a series. Later, each pot was planted with 9 hand-shelled, untreated peanut seed of the Dixie Spanish variety. After planting, each series of eighteen pots was divided into three groups of 6, each to receive a respective application of sesone. These six pots may be compared to the replicates in field plot studies.

All tests were carried out in a greenhouse where minimum air temperatures were controlled at 80° F, while maximum temperatures were more variable because of manual control of ventilation and differences between seasons of the year. All tests were held for observation at least 12 days after planting.

The data from the 24 series of 18 pots each were arbitrarily

divided into three classes for purposes of discussion. These classes represent three segments of a gradient in emergence and should not be confused with classes based on three specific or absolute points in the technique. This technique and the gradient in disease or emergence has been described and is not the case in point in this study (1). Therefore, it is assumed that with respect to the factor for emergence due to disease, the three groups of 6 pots each formed by random selection from a uniformly prepared series are reasonably comparable.

The classes of series were formed to illustrate the frequency in direction of difference between different rates of sesone as well as the magnitude of these differences in different segments or levels in the gradient for emergence due to disease. It must be remembered that the checks form a gradient and this gradient is being compared with the gradient obtained in the comparable plantings treated with sesone.

EXPERIMENTAL RESULTS

The data from all tests were tabulated and compared according to the percentage of emergence obtained in the respective control planting that received no sesone (Table 1). Series of pots where more than 80 percent emergence was obtained from control plantings are included in Class I. Series with control plantings that range between 70 to 80 percent are included in Class II. All series with controls below these levels are included in Class III.

In the Class I series, with stands that a farmer would ordinarily consider as satisfactory, there was no significant deleterious effect from the sesone. The emergence in the treated plantings was equal to or greater than the control in 10 out of 24 chances, and the range of differences was about equal in either direction.

Class II may be described as in a transitional level between severe and slight disease. In this class, the treated plantings exceeded their respective controls in only 5 out of 16 possible chances. The maximum difference in percentage of emergence in this direction was 11.1. In the opposite direction, 11 of the 16 treated plantings had an emergence less than the respective control. The maximum difference in percentage was 61.1 as compared to the 11.1 noted above. This group shows a very distinct trend toward the deleterious combined effect of sesone under conditions favorable to disease.

The tests in Class III without exception, show the deleterious effect of the combined action of disease and sesone on emergence. All tests in this class were under circumstances previously reported to be favorable to both the development of disease and the reduction of emergence (1).

SUMMARY

These tests illustrate the combined action of sesone and disease on the emergence of peanuts under conditions favorable to the action of soil inhabiting organisms. However, this phenomenon is not proposed to explain all failures to obtain a satisfactory stand after the use of sesone. In a limited number of cases, a similar effect has been noted when seed of low vitality had been used. The problem does

Table 1. The effect of disease and sesone on the emergence of peanut seedlings.

Untreated	Sesone application—lb/A					
	3			6		
Emergence[a] %	Emergence[a] %	Difference[b] from untreated +	Difference[b] from untreated −	Emergence[a] %	Difference[b] from untreated +	Difference[b] from untreated −
		Class I. 80–100 percent[c]				
100.0	98.1	—	1.9	94.4	—	5.6
98.1	96.3	—	1.8	96.3	—	1.8
96.3	87.0	—	9.3	90.7	—	5.6
96.3	90.7	—	5.6	90.7	—	5.6
96.3	81.5	—	14.8	79.6	—	16.7
94.4	87.0	—	7.4	94.4	—	0.0
94.4	96.3	1.9	—	88.9	—	5.5
92.6	88.9	—	3.7	96.3	3.7	—
88.9	90.7	1.8	—	90.7	1.8	—
87.0	90.7	3.7	—	91.4	7.4	—
85.2	90.7	5.5	—	79.6	—	5.6
81.5	88.3	6.8	—	94.4	12.9	—
Av. 92.6	90.1	—	2.5	90.9	—	1.7
		Class II. 70–80 percent[c]				
79.6	53.7	—	25.9	38.9	—	40.7
79.8	87.0	9.2	—	66.7	—	11.1
75.9	59.3	—	16.6	53.7	—	22.2
74.1	14.8	—	59.3	13.0	—	61.1
73.1	46.3	—	26.8	35.2	—	37.9
75.2	68.5	—	3.7	77.8	5.6	—
72.2	66.7	—	5.5	83.3	11.1	—
70.4	75.9	5.5	—	74.1	3.7	—
Av. 74.4	59.0	—	13.4	55.3	—	19.1
		Class III. Below 70 percent[c]				
53.7	22.7	—	31.0	5.6	—	48.1
40.7	9.3	—	31.4	1.9	—	38.8
29.6	7.4	—	22.2	16.7	—	12.9
5.6	1.9	—	3.7	0.0	—	5.6
Av. 32.4	10.1		22.3	6.1		26.3

[a]Emergence as percent based on 54 seed (6 pots each containing 9 seed) planted in each case.
[b]Difference, plus and minus with respect to untreated control.
[c]Class of test based on percent emergence obtained in respective untreated control.

not appear to be whether or not sesone alone is deleterious to emergence, but what factors may work in combination with sesone to reduce the emergence of peanut seedlings. These findings indicate another reason to emphasize the importance of tillage to reduce disease by completely burying all organic trash in the preparation of land for peanuts (2).

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Correlation and Cooperation Between Agencies in Weed Control in Minnesota

SIG. BJERKEN[1]

IN THE field of weed control many complications are encountered as the program is carried out. In order to make progress, the combined efforts of research, extension, industry and the regulatory forces are necessary to provide the farmers and other people concerned with weed control with the information and material required by them to carry out an effective program. Research workers must provide us with their findings so that proven practices and techniques for controlling grassy and broadleaf weeds can be used.

The proper utilization of the array of herbicides available is largely in the hands of our educational leaders. Extension workers, in particular, must continue to keep abreast of research findings. They must be able to demonstrate and sell the desirability of the new techniques to the people. Research findings nicely bound and filed are of little value to the farmer and land owner unless incorporated into our common usage. Through the medium of television, radio, educational meetings and the press it is possible to reach the people and furnish them with information useful to them in the control of weeds.

Industry has provided an increasing number of selective and non-selective herbicides. The public has accepted these improved chemicals and it has therefore been possible to make great strides in weed control. Equipment which is more practical and efficient has been most helpful in selling the program to those concerned with weed control.

Regulatory people have served to guide our actions and maintain our objective. They stand as the first line of defense against the introduction of new weeds and provide the necessary supervision which is so essential in a weed control program. In carrying out an effective state-wide eradication program it is essential that the cooperation of various agencies be enlisted to aid in the cause. A number of those who have played an important part in the State of Minnesota should be mentioned.

The Agricultural, Stabilization and Conservation Agency has under its jurisdiction considerable acreage in Minnesota. This land, as in any other state, involves weed problems. The ASC organization is well aware of the problems and recognizes the importance of acquainting the participants with the requirements of the Weed Law for their own protection as well as for the protection and welfare of other participants. Through the close cooperation of the ASC office and the 87 county committees each participant is notified in due time as to the requirements in respect to his weeds. The result is that the county committee along with the county weed supervisor

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work closely with those participating in each county and no serious weed difficulties are encountered. Cooperation of this kind contributes to a more successful program.

The State Conservation Department, through its activities has contributed immensely to the weed program and rightly so because it is responsible for a considerable acreage of the state's area, practically all of which is subject to becoming infested with weeds. It would be wasted effort, and uncalled for, to expect the farmers to control their weeds if on the other hand the state agencies do not comply with the provisions of the Weed Law. The Minnesota legislature recognizes this fact and appropriates funds annually for the control of weeds on such lands as are a menace to agriculture. Within the Conservation program a considerable acreage of lowlands is being purchased. This land, known as Wetlands, may in some instances present a weed problem. The conservation officials in cooperation with the regulatory group carry out an active program of weed control. The Conservation Department also has an aquatic weed control program in close cooperation with the Department of Agriculture. Through this united action the program is being readily accepted by the people of Minnesota.

The alarming spread of wild hemp or marijuana and the increasing use of the drug by a considerable number of the youth of the United States has aroused national concern. The authorities of the federal government responsible for the prevention of crime recognize the close relationship of the use of this drug and crime throughout the nation. It is apparent that before much can be done to eliminate crime we must deal with the root of the problem. The citizens of any state cannot afford to stand idly by if hemp is growing in their state without taking action. Something can be done and in Minnesota an organized eradication program is under way in all of the 87 counties of our state. The cooperation extended by the Bureau of Narcotics has been most helpful. They report that while complaints continue to increase from other states it is the reverse in Minnesota.

Minnesota has some 805,000 acres known as Indian lands, of which 29,000 acres are cropland. Such lands harbor weed infestations which are a menace to agriculture. The Indian Affairs Bureau provides funds for the control of weeds on land under its jurisdiction and the control program is carried out by the State Department of Agriculture through an agreement between the Bureau of Indian Affairs and the Minnesota Department of Agriculture. The program is paid for from funds provided by the Bureau of Indian Affairs. It is important to have a state-wide program with an organized program in each of the counties. Agencies, under such a program, are prone to cooperate much more readily and rightly so.

Those in charge of the maintenance of powerlines, railroads, pipelines, telephone company rights-of-way, etc. have been most cooperative in the field of weed and brush control. Their officials realize that weeds on their rights-of-way, if not controlled, will eventually infest adjacent property and affect the revenue from such lands.

which indirectly affects their welfare. Those in charge of maintenance of highways have carried out an effective weed control program on their rights-of-ways, which has been most helpful in encouraging those who live along such roads to do likewise, while otherwise many would be reluctant to cooperate.

In summary it should be emphasized that it is important to have a weed control program that is state-wide. It must be a program that commands the united support of extension, research, industry and regulatory people, along with all other agencies lending their support. The program must have good supervision, prompt service must be rendered and personal contacts must be made with those who have weed problems. There are many recommendations to offer today. In most cases every acre of cropland may be cropped regardless of the seriousness of the weed provided the right crop is planted and the proper chemical or practice is applied.

Minnesota may be cited as an example. It is a state consisting of 51,000,000 acres, divided into 87 counties, 1840 townships, and 915 villages or cities. All of the 87 county boards appoint a county weed supervisor, 50 per cent on a full time basis. The three supervisors of the 1840 townships and the mayors of the 915 villages or cities are weed inspectors by law. Assistants may be appointed. In 1957 some 7,000 inspectors served. Ninety-one county-wide meetings were held in the 87 counties. A 5 day short course was held as a training course for the state and county inspectors. Following the county-wide meetings the county inspectors and county agents proceed to hold organization meetings with the township boards and meet with the tenants and owners of problem farms before the seeding of crops. Educational meetings are held in many of the townships. Minnesota has a law which makes it possible to bring about weed eradication on any tract of land whether it is federal or state, private or public, taxable or non-taxable. Any weed that is harmful to crops comes under the law. The Weed Law was strengthened by the 1957 legislature by a vote of 122 to 0 in the House and 55 to 0 in the Senate. Weeds are still present in Minnesota, but in 1957 over 4,338,000 acres, or 36 per cent of the cropland was sprayed.

Regulatory Work in Kansas

JAKE R. UBEL[1]

KANSAS has just completed the twentieth year of its organized program for the control of noxious weeds. The Kansas Noxious Weed Law was passed in 1937 by the State legislature. At that time, field bindweed, *Vonvolvulus arvensis,* was recognized as a menace to agriculture and the law was passed to provide for an organized fight against this weed. The law at that time contained provisions only for control and eradication measures of that one weed. In 1945, it was foreseen that a program which did not include "preventive" measures was inadequate. Provisions were then added to the law which made it unlawful to sell or offer for sale, unless processed to destroy the viability of the noxious weed seeds, grain and hay (livestock feed material), screenings, nursery stock, soil and sod containing seeds of noxious weeds.

Two weeds were added to the noxious list by 1945 Legislature; hoary cress, *Lepidium draba,* and Russian knapweed, *Centaurea picris.* At that time, the law gave the county commissioners the option of declaring Johnsongrass, *Sorghum halepense,* a noxious weed. To date, these officials have exercised their authority in 77 of the 105 counties in Kansas.

Originally the Noxious Weeds Division of the State Board of Agriculture was created by administrative action. The 1957 Legislature amended that particular section of the law and the Division now exists by statute. The Division administers the law on the state level and supervises administration and enforcement of the law on the county level. At the present time, the Division has five fieldmen who are constantly traveling in their respective areas to advise, consult and otherwise render assistance and direction to county and city weed supervisors as to the best and most practical methods of noxious weed control and eradication. It is their duty also to aid in the investigation and prosecution of violations, prepare records and reports, assist the county men with meetings and in making contacts, prepare budgets, and advise in planning the county program.

The Kansas law provides that commissioners of each county shall appoint a competent person each year to the position of county weed supervisor. The appointment is made with the approval of the Board of Agriculture. The salary of the county weed supervisor and other needed funds are provided by county appropriation. The noxious weed fund is in addition to all other levies and as provided by law, is not to exceed one mill. To date, no county appropriation has ever approached the maximum of one mill. County budgets vary considerably. For 1958, one county budgeted nearly $40,000, but the large percentage of counties fall in the $10,000 to $20,000 range. The total amount of money budgeted by counties in 1957 was nearly $1,333,000; for 1958, in excess of $1,403,000. The total amount of

[1]State Weed Supervisor, State Board of Agriculture, Topeka, Kansas.

money budgeted by Kansas counties for the 20 year period, 1938 thru 1957 was about $12,500,000.

One provision of the law provides: "That chemical materials for use on privately owned lands may be purchased from the board of county commissioners at one-half the total cost thereof." The county weed supervisor must make surveys and try to anticipate in advance the chemical materials that will be needed for the coming year, then budget for them, submit the orders and keep records of the disbursements. Disbursements in 1956 by the county men were as follows:

Sodium chlorate	1,058 tons
Borates & borate-chlorate mixtures	586 tons
Salt	552 tons
	2,196 tons of soil sterilants
2,4–D	205,600 lbs.

The amounts of chemicals disbursed in both 1955 and 1956 were not noticeably different except that the amount of sodium chlorate decreased slightly in 1956 from 1955. This was probably a result of the prolonged dry period. Almost equivalent amounts of 2,4–D were used in 1955 and 1956.

The Board of Agriculture is empowered by law to decide upon and adopt, as official, methods for the control and eradication of noxious weeds. Included in the official methods are intensive cultivation, smother cropping and combinations of the two. Chemicals officially approved for use are sodium chlorate, boron compounds, mixtures of borate and chlorate, 2,4–D (2,4–dichlorophenoxyacetic acid), TCA (trichloroacetic acid), monuron [3–(p–chlorophenyl)–1, 1–dimethyl urea], dalapon (2,2–dichloroproprionic acid) and erbon [2–(2,4,5–trichlorophenoxy)ethyl 2,2–dichloroproprionate]. It is the county weed supervisor's duty to encourage the use of official methods. These methods and chemicals have been tried and have proved to be effective and satisfactory for the control of a particular weed or weeds as prescribed by the regulation.

The weed law places the responsibility and the obligation of controlling and eradicating noxious weeds with the owner or individual, firm, or corporation having supervision of land where the weeds are located. The law does not specify that it is the county weed supervisor's duty to do the treating. It would be unreasonable to expect the county weed supervisor to accept and assume that responsibility unless, of course, he were provided with enough funds to purchase equipment and employ a staff for the job. In counties where the necessary equipment is available, the county department does a lot of the actual application work. However, the amount of spraying to be done is so great that it is necessary for the farmers to do much of their own application work. County weed supervisors are encouraged to do more informative and educational work and encourage more landowners to do their own treating.

The noxious weeds belong to the landowner. They are his responsibility, both from a logical and practical standpoint. The state

officials do not feel, and neither should the county weed supervisors feel, that a landowner's noxious weeds are the problem of those administering the law. The problem is to assist and help those who have the weeds to help themselves. In 1956, county weed supervisors' annual reports listed 4,771 farmer-owner and commercial ground spray machines in Kansas. It seems certain that greater progress will be made by encouraging the farmers to use their own equipment, at the proper time, to apply the logical and correct chemical at the proper rate. A program of this type appears to be sound and practical.

The non-cooperator is a problem in all enforcement programs. The law provides that if a landowner fails to comply with the act in the control and eradication of weeds in any current year, he shall be given written notice of that evidence and the notice shall state that unless he proceeds to control the noxious weeds, the county commissioners will after 15 days from the date specified in said notice, enter or cause to be entered upon the infested property and use approved methods to control and eradicate the weeds. The county men of course use the law as a last resort. In other words, all other possible methods are to be used first to get the landowner to work on his noxious weeds. If that fails, then the "legal notice" system is used.

A similar procedure can be used with reference to unpaid accounts, outstanding by December 21 of each year. The law requires that the landowner be notified with an itemized statement of his unpaid account. If the amount is not paid within thirty days from the date of the notice, the amount becomes a lien against the real estate and can then, according to prescribed legal procedure, be spread upon the tax rolls and be collected as other taxes are collected. Weed enforcement men serve legal notices but rarely; likewise, only on rare occasions is it necessary to place a delinquent bill upon the tax rolls in order to collect.

The program would not be complete without "preventive measures". The Kansas law contains five separate and distinct provisions making it unlawful to sell or dispose of materials such as screenings, feed grain, hay, nursery stock, soil, sod, animal fertilizer or packing material which contain seeds of noxious weeds. One of these sections has to do with the movement of farm machinery into the state or from infested fields or farms within the state that is infested with seeds of noxious weeds. Farm machines, specifically harvesting equipment, portable feed grinders, portable seed cleaners, or field ensilage cutters, must be free of all weed seed and litter if they are to be moved lawfully from infested fields or farms within the state.

How are these provisions administered? They are publicized in the local papers together with news articles explaining why it is important to exercise precaution with respect to scattering noxious weed seeds. Almost without exception, when people learn of noxious weeds through contacts by the county weed supervisor, through meetings, letters, radio and television, they become more conscious of the hazards that noxious weeds offer. When they learn how they will benefit, they begin to put the recommended measures into practice.

The prevention portion of the program and of the law is most useful. County weed supervisors have made the following numbers of inspections of feed grain, hay, and nursery stock in recent years:

1954 — 11,607
1955 — 18,593
1956 — 23,376

Some workers believe that money spent to prevent the establishment of noxious weeds are the best dollars spent.

To summarize briefly, weed enforcement officials prefer to work cooperatively with people, to inspire them and encourage them to act, to teach rather than to enforce, and to do something for them rather than to them. Legal pressure is brought to bear only when all other means fail.

Erratum

Volume 5, Issue 3:

Page 210. The second and third lines read ". . . *phosphotungstic acid, solution. Centrifuge. . . .*" and should read "*. . . phosphotungstic acid. Centrifuge and add 1 ml. of silver solution. Centrifuge. . .*"

News and Notes

The officers and meeting dates for the various weed conferences are as follows:

Northeastern Weed Control Conference;

President—S. N. Fertig, Cornell University, Ithaca, New York.
Vice president—L. G. Utter, Diamond Alkali Co., Painesville, Ohio.
Secretary-treasurer—Donald Schallock, Rutgers University, New Brunswick, New Jersey.
Next meeting—January 6, 7 and 8, 1959 at the Hotel New Yorker, New York City.

Southern Weed Conference;

President—Richard Behrens, Crops Research Division, ARS, USDA, College Station, Texas.
Vice president—V. S. Searcy, Alabama Agricultural Exp. Station, Auburn, Alabama.
Secretary-treasurer—W. K. Porter, Jr., Louisiana State University, Baton Rouge, Louisiana.
Next meeting—January 21, 22 and 23, 1959 at the Washington Youree and Captain Shreve Hotels, Shreveport, Louisiana.

Western Weed Control Conference;

President—R. A. Fosse, American Chemical Paint Co., Denver, Colorado.

Vice president—W. R. Furtick, Oregon State College, Corvallis, Oregon.

Secretary-treasurer—E. E. Heikes, Montana State College, Bozeman, Montana.

Next meeting—February 22–25, 1960, Cosmopolitan Hotel, Denver, Colorado, when the conference acts as host for the third meeting of the WSA.

North Central Weed Control Conference;

President—Lyle Derscheid, South Dakota State College, Brookings, South Dakota.

Vice president—J. R. Foster, Experimental Farm Service, Indian Head, Saskatchewan, Canada.

Secretary-treasurer—D. W. Lambert, State Dept. of Agriculture, State Capital, Lincoln, Nebraska.

Next meeting—December 3 and 4, 1958, Netherlands Hilton Hotel, Cincinnati, Ohio.

Richard Behrens has accepted a position dealing with weed control in field crops in the department of Agronomy and Plant Genetics, University of Minnesota, St. Paul. He was formerly with the Crops Research Division, ARS, USDA and stationed at College Station, Texas.

The National Science Foundation has awarded a grant of $23,900 to North Carolina State College for a research project entitled "The Uptake of Organic Chemicals by Plant Roots". The grant is for a period of 3 years and will be directed by R. P. Upchurch.

Raymond A. Evans has accepted a position with the Crops Research Division, ARS, USDA and will collaborate with the College of Agriculture, University of Nevada, Reno, on the control of range weeds, especially halogeton. He was formerly with the Dept. of Agronomy, University of California in Davis.

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for
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This bibliography of current literature on weeds and their control is issued as a service to those engaged in weed research in the United States and other countries. In issuing this bibliography the Crops Research Division, Agricultural Research Service, U.S.D.A. does not assume responsibility for the subject matter cited.

Beltsville, Maryland

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